Shuttle Ground Operations Efficiencies/Technologies Study

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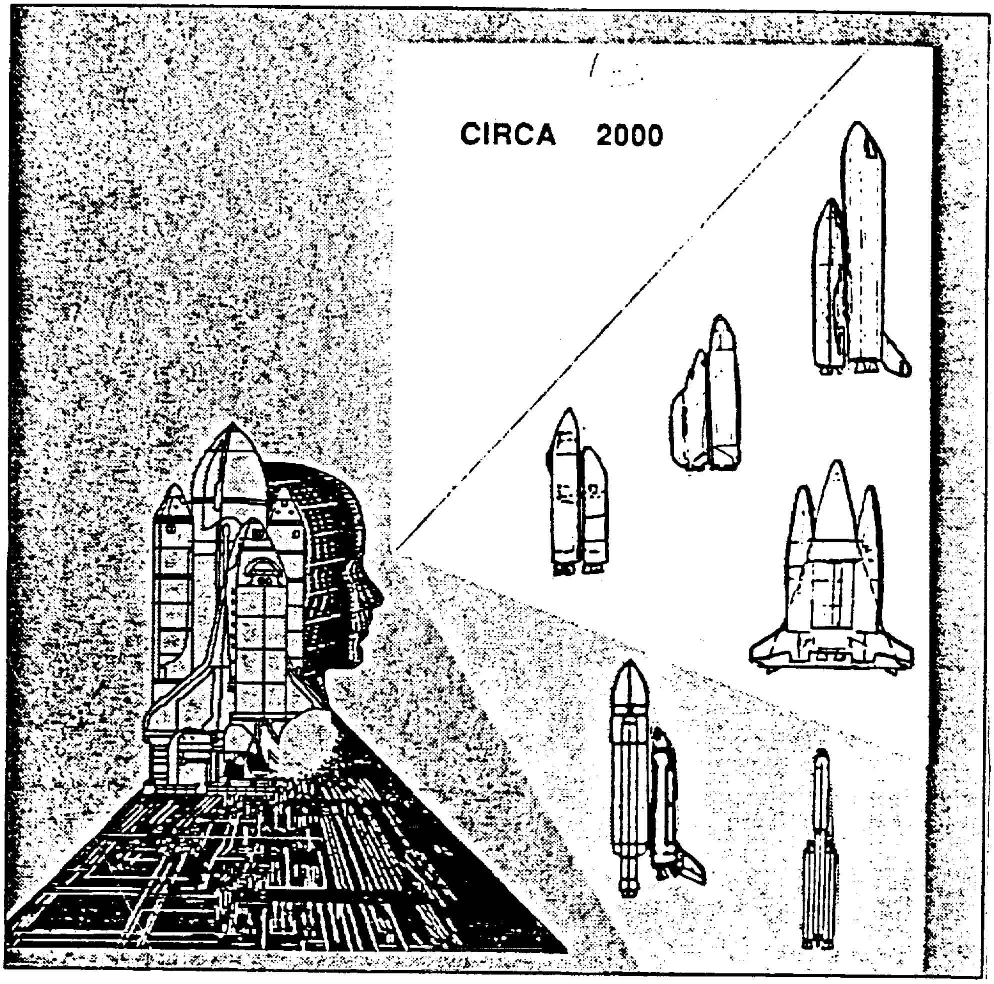
AEROSPACE OPERATIONS



FINAL REPORT PHASE 2
Volume 3 (Part 1) of 6

SPACE-VEHICLE OPERATIONAL COST-DRIVERS HANDBOOK SOCH

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SHUTTLE GROUND OPERATIONS EFFICIENCIES / TECHNOLOGIES STUDY
PHASE 2 FINAL REPORT

STUDY REPORT

Volume 1 EXECUTIVE SUMMARY
The Executive Summary provides an overview of major elements of the Study. It summarizes the Study analytic efforts, the documentation developed, and reviews the recommendations resulting from the analyses conducted during Phase 2 of the Study.

Volume 2 PHASE 2 FINAL ORAL PRESENTATION
The Final Presentation Material volume contains the charts used in the Final Oral Presentations for Phase 2, at KSC on April 6, 1988. A brief, overall review of the Study accomplishments is provided. An indepth review of the documentation developed during the last quarter of Phase 2 of the Study is presented. How that information was used in this Study is explained in greater detail in Vols. 3 and 4. An initial look at the topics planned for the upcoming Workshops for Government/Industry is presented along with a cursory look at the results expected from those Workshops.

Volume 3 SPACE-VEHICLE OPERATIONAL COST DRIVERS HANDBOOK (SOCH)
The Space-vehicle Operational Cost drivers Handbook (SOCH) was assembled early in Phase 2 of the Study as one of the fundamental tools to be used during the rest of the Phase. The document is made up of two parts -- packaged separately because of their size.

Part 1 Presents, in checklist format, the lessons learned from STS and other programs. The checklist items were compiled so that the information would be easily usable for a number of different analytical objectives, and then grouped by disciplines or gross organizational, and/or functional responsibilities. Content of the checklists range from 27 management; 11 system engineering; 8 technology; and 19 design topics -- with a total of 793 individual checklist items. Use of this Handbook to identify and reduce Cost Drivers is recommended for designers, Project and Program managers, HQ Staff, and Congressional Staffs.

Part 2 Contains a compilation of related reference information about a wide variety of subjects including ULCE, Deming, Design/Build Team concepts as well as current and previous space launch vehicle programs. Information has been accumulated from programs that range from, Saturn/Apollo, Delta, Titan, and STS to NASP and Energia.

Volume 4 SIMPLIFIED LAUNCH SYSTEM OPERATIONAL CRITERIA (SLSOC)
The SLSOC document was developed from the generic Circa 2000 System document, Vol. 6; is similar in content; and also indicates the manpower effect of the elimination of many STS-type cost drivers. The primary difference between the two documents is the elimination of all generic Circa 2000 requirements (and support) for manned-flight considerations for the ALS vehicle. The data content of the two documents, while similar in nature, was reorganized and renumbered for SLSOC so that it could be used as the basis for various panels and subpanels in an ALS Workshop.

PHASE 2 STUDY REPORT (Cont'd)

Historical data is the basis for the conclusion that incremental improvements of technology and methods cannot significantly improve LCC (by an order-of-magnitude) without major surgery. A system enabling the development of a radically simplified operational concept, reflected in SLSOC, was included so that proposed designs (and operations) could be compared to systems providing for simplicity -- rather than the current STS complexity.

The identified operational cost drivers from STS plus other historical data were used as background reference information in the development of each example concept designed to eliminate cost drivers. These example concepts, when integrated, would support an order-of-magnitude cost reduction in current (STS), exorbitant Life Cycle Costs (LCC). Individual operational requisites were developed for each element in the associated management systems, integration engineering, vehicle systems, and supporting facilities. These have associated rationale, sample concepts, identification of technology developments needed, and technology references to abstracts. The technology abstracts are provided in a separate volume, Vol. 5.

Technology changes almost daily, thus past trade studies may no longer be valid. In addition, old "trades" often used inaccurate estimates of "real" operational costs. Vehicle designs are compromises and have been performance oriented with operations methods/techniques based on those designs. It is the intent of our example concepts in the SLSOC to stimulate design teams to improve or replace conventional design approaches. Obviously, it is up to the responsible program design teams to provide design solutions to resolve operational cost drivers.

Volume 5 TECHNOLOGY REFERENCES

This document provides a repository for the Technology References for the SLSOC and the CIRCA 2000 System documents. The technology references, mostly from NASA RECON, are supplied to the reader to facilitate analysis on either the SLSOC or the CIRCA 2000 System documents. Some data references were also obtained via DIALOG. If more technical information is desired by an analyst, he must obtain the additional documentaiton thru his library or from some other appropriate source. The XTKB (EXpanded Technology Knowledge Base) provided a user-friendly tool for our analyses in identifying and obtaining the computerized database reference information contained in this document. Thousands of abstracts were screened to obtain the 300 plus citations pertinent to SLSOC in this Volume.

Volume 6 CIRCA 2000 SYSTEM OPERATIONAL REQUIREMENTS

The Circa 2000 System Operations Requirements were developed using STS as a working data source. We identified generic operations cost drivers resulting from performance-oriented vehicle design compromises and the operations methods/techniques based on those designs. Those Cost Drivers include high-cost, hazardous, time & manpower-consuming problem areas involving vehicles, facilities, test & checkout, and management / system engineering. Operational requisites containing rationale, example concepts, identification of technology developments needed, and identification of technology references using available abstracts were developed for each Cost Driver identified. Elimination of cost drivers significantly reduces recurring costs for prelaunch processing and launch operations of space vehicles.

NOTE: Volumes 1,3,4 and 5 are being widely distributed. Volume 2 is a copy of presentation material already distributed and Volume 6 will be distributed only on request. Copies of the full report will be placed in libraries at NASA HQ., JSC, KSC, MSFC and NASA RECON. Individual volume copies may be obtained by forwarding a request to W. J. Dickinson, KSC PT-FPO, (407) 867-2780.

SPACE-VEHICLE OPERATIONAL
COST-DRIVERS HANDBOOK (SOCH)

Volume 3 (Part 1) of 6
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See Volume 3, Part 2, (separate volume)
SGOE/T Final Report, Phase 2

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ACRONYMS and ABBREVIATIONS

$B	Dollars-billions
$M	Dollars-millions
AFD	Aft Flight Deck
AFSATCOM	Air Force Satellite Communications
AFSCF	Air Force Satellite Control Facility
AFSCN	Air Force Satellite Control Network
AFSCF/STC	Air Force Satellite Control Facility/Space Test Ctr.
AGCS	Automatic Ground Control System
AH	Ampere-Hour
AI	Artificial Intelligence
Al	Aluminum
Al-Li	Aluminum-Lithium
AOA	Abort Once Around
APU	Auxiliary Power Unit
ASE	Airborne Support Equipment
ASSY	Assembly
ATC	Air Traffic Control
ATE	Automatic Test Equipment
ATKB	Automation Technology Knowledge Base
ATO	Abort to Orbit
ATPG	Automatic Test Program Generation
A50	Aerozine 50 (50% Hydrazine and 50% UDMH)
BIT	Built-In-Test
BITE	Built-In-Test-Equipment
BSTR	Booster
C	Celsius; Carbon
C2K	Circa 2000
C_3H_8	Propane
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAI	Computer Aided Instruction
CALS	Computer Aided Logistics System
CAM	Computer Aided Manufacturing
CDDT	Countdown Demonstration Test
CDF	Confined Detonating Fuse
CECO	Center Engine Cutoff
CELV	Complimentary Expendable Launch Vehicle (now Titan IV)
CG	Center of Gravity
CH_4	Methane
CIM	Computer Integrated Manufacturing
CITE	Cargo Integration Test Equipment
CIU	Computer Interface Unit
CM	Command Module
C/O	Checkout
COMM	Communications
COMM SAT	Communication satellite
CPU	Central Processing Unit
CPV	Combined Pressure Vessel
CR	Control Room
Cryo	Cryogenic
CSOC	Consolidated Space Opertions Center
CT	Crawler Transporter
CTS	Common Tank Set
CV	Cargo Vehicle
CVD	Chemical Vapor Deposition

ACRONYMS and ABBREVIATIONS
(Continued)

DA	Data Acquisition
D/A	Digital/Analog
DAS	Data Acquisition System
DB	Data Base
DBMS	Data Base Management System
DBS	Direct Broadcast Satellite
DBT	Design Build Team
dc	Direct Current
DCA	Defense Communications Agency
DDT&E	Design, Development, Test and Evaluation
DFT	Design For Testability DMS Data Management System
DOD,DoD	Department of Defense
DOMSAT	Domestic Communication Satellite
DPS	Data Processing System
DR	Discrepancy Report
DSCS	Defense Satellite Communication System
DSN	Deep Space Network DSP Defense Support Program
DTC	Design to Cost
ECLSS	Environmental Control & Life Support System
ECS	Environmental Control System
EECOM	Electrical, Environmental, Communications
EIU	Engine Interface Unit
ELS	Eastern Launch Site
ELV	Expendable Launch Vehicle
EMC	Electro Magnetic Compatibility
EMU	Extravehicular Mobilility Unit; Extended Memory Unit
EPD&C	Electrical Power Distribution and Control
EPS	Electrical Power Subsystem
ES	Expert System
ESS	Energy Storage System
E/T	External Tank
ETR	Eastern Test Range
EVA	Extravehicular Activity
FAA	Federal Aviation Administration
FCE	Flight Crew Equipment
FCM	Fuel Cell Module
FDO	Flight Dynamics Officer
FMS	Flight Management System
FRCS	Forward Reaction Control System
FSS	Flight Systems Simulator
FWC	Filament Wound Case
FY	Fiscal Year
GB	Ground Based
GD	General Dynamics
GEO	Geosynchronous Orbit
GFS	Government Furnished Support
GH2, GH_2	Gaseous Hydrogen
GLOW	Gross Liftoff Weight
GN&C,G&C	Guidance Navigation and Control
GN_2	Gaseous Nitrogen
GO	Ground Operations
GO2,GO_2	Gaseous Oxygen
GPM	Gallons Per Minute
GPS	Global Positioning Satellite
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center

ACRONYMS and ABBREVIATIONS
(Continued)

GSTDN,STDN	Ground Station Tracking and Data Network
HC	Hydrocarbon
He	Helium
HEO	High Earth Orbit
HIF	Horizontal Integration Facility
HLLV	Heavy Lift Launch Vehicle
HPFTP	High Pressure Fuel Turbo Pump
HTO	Horizontal Take Off
H/W	Hardware
H_2	Hydrogen
HYD	Hydraulic(s)
IC	Integrated Circuit
IDSS	Integrated Design Support System
I/F	Interface
IMIS	Integrated Maintenance Information System
IFA	In-flight Anomaly
ILS	Integrated Logistics System
IMU	Inertial Measurement Unit
INCO	Instrumentation and Communications Officer
INEL	Idaho National Engineering Laboratory
INS,INST	Instrumentation
INT	Integration
IOC	Initial Operational Capability
I/O	Input/Output
IPR	Interim Problem Report
IPV	Individual Pressure Vessel
IR	Infrared
IR&D	Independent Research and Development
IRR	Internal Rate of Return
Isp	Specific Impulse
IU	Interface Unit
IUS	Inertial Upper Stage
JSC	Johnson Space Center
K	Thousand
KEW	Kinetic Energy Weapon
KSC	Kennedy Space Center
KW	Kilowatt
LAN	Local Area Network
LBS	pounds
LCA	Launch Control Amplifier
LCC	Life Cycle Cost
LCCV	Low Cost Cargo Vehicle (MMC)
LCE	Low Cost Expendable
LCEP	Low Cost Expendable Propulsion
LC-Titan	Large Core Titan
LDC	Large Diameter Core
LEM	Lunar Excursion Module
LES	Launch Escape System
LEO	Low Earth Orbit
LH	Left Hand
LH2,LH2	Liquid Hydrogen
Li-$SOCl_2$	Lithium Sulphur Oxygen Chlorine
Li	Lithium
LN_2	Liquid Nitrogen
LO2,LO_2	Liquid Oxygen

ACRONYMS and ABBREVIATIONS
(Continued)

LPS	Launch Processing System
LRBs	Liquid Rocket Boosters
LRE	Liquid Rocket Engine
LRU	Line Replaceable Unit
LSC	Linear Shaped Charge
LV	Launch Vehicle
L&L	Launch and Landing
M	Million
MC	Mission Control
MCC	Main Combustion Chamber
MCR	Modification Change Request
MCS	Mission Control System
MCT	Mission Control Teams
MDAC	McDonnell Douglas Astronautics Company
MDM	Multiplex/De-multiplex
ME	Main Engine; Maintenance Expert
MELV	Medium Expendable Launch Vehicle
MEO	Medium Earth Orbit
MFRCV	Manned Fully Reusable Cargo Vehicle(s) (STS II)
MFRGB	Manned Fully Reusable Ground Based-OTV
MFRSB	Manned Fully Reusable Space Based-OTV
MILSTAR	Military Transmission and Relay Satellite
MLP	Mobile Launcher Platform
MMC	Martin Marietta Company
MMMA	Martin Marietta Michoud Aerospace
MMU	Manned Maneuvering Unit
MPM	Manipulator Positioning Mechanism
MPRCV	Manned Partially Reusable Cargo Vehicle
MPS	Main Propulsion System
MPSR	Multipurpose Support Room
MPST	Multipurpose Support Team
MSBLS	Microwave Scanning Beam Landing System
MSFC	Marshall Space Flight Center
MS/NAS	Machine Screw/National Aircraft Standard
MTBF	Mean-Time Between Failure
MTTR	Mean-Time to Repair
NaS	Sodium Sulphur
NAS	National Airspace System
NA-S	National Aircraft Standard
NASA	National Aeronautics and Space Administration
NASA/RECON	Remote Console (NASA information retrieval system)
NCCS	Network Communication and Control Stations
NCS	Network Control Stations
NDE	Non-Destructive Evaluation
NDT	Non-Destructive Test
Ni-Cd	Nickel-Cadmium
NiCad	Nickel Cadmium
NIH	Not Invented Here
$Ni-H_2$	Nickel-Hydrogen
NiTi	Nickel-Titanium
Nitinol	Nickel-Titanium-Naval Ordnance Laboratory
NLG	Nose Landing Gear
NORAD	North American Air Defense
NSI	NASA Standard Initiator
N_2H_4	Hydrazine Monopropellant
N_2O_4	Nitrogen Tetroxide

ACRONYMS and ABBREVIATIONS
(Continued)

OAA	Orbiter Access Arm
OBECO	Outboard Engine Cutoff
O&M	Operations and Maintenance
OMI	Operations and Maintenance Instruction
OMP	Operationsand Maintenance Plan
OMRSD	Operational Maintenance Requirements and Specifications Document
OMS	Orbital Maneuvering System
OMV	Orbital Maneuvering Vehicle
OPC	Operations Planning Center
OPF	Orbiter Processing Facility
OPS	Operations
ORB	Orbiter
ORU	Orbiter Replacement Unit; Orbital Repaired Unit
OTV	Oribital Transfer Vehicle
OV	Orbiter Vehicle
P/A	Propulsion/Avionics Module
PAM	Payload Assist Module; Payload Applications Module
PAREC	P/A Recovery Area
PC	Printed Circuit
PCBS	Printed Circuit Boards
PCP	Power Control Panel
PCR	Payload Changeout Room
PDI	Payload Data Interleaver
PDR	Preliminary Design Review
PFLB	Pressure Fed Liquid Booster
P/FRCV	Partially/Fully Reusable Cargo Vehicle
PGHM	Payload Ground Handling Mechanism
PGOC	Payload Ground Operations Contractor (MDAC)
PIC	Pyro Initiator Controller
PIDB	Preliminary Issues Database
PL, P/L	Payload
PLB	Payload Bay
PLF	Payload Fairing or Payload Facility
POCC	Payload Operations Control Center
POI	Product of Inertia
PR	Problem Report
PRCBD	Program Review Control Board Directive
PRSD	Power Reactant Storage and Distribution
PSA	Payload Support Avionics
PSI	Pounds Per Square Inch
PSP	Processing Support Plan
PV	Present Value
PV&D	Purge, Vent and Drain
QA	Quality Assurance
QC	Quality Control
QD	Quick Disconnect
RADC	Rome Air Development Center
RAMCAD	Reliability and Maintainability through Computer Aided Design
RCC	Reinforced Carbon Carbon
RCS	Reaction Control System
R&D	Research and Development
RECON	Remote Console (NASA information retrieval system)
RF	Radio Frequency
RFCS	Regenerative Fuel Cell System
RFP	Request for Proposal

ACRONYMS and ABBREVIATIONS
(Continued)

RH	Right Hand
RIC	Rockwell International Corporation
RJDA	Reaction Jet Drawer
RMS	Remote Manipulator System
R&PM	Research and Program Management
RPSF	Remote Processing and Storage Facility(s)
RP-1	Rocket propellant-JP-X based
R/R,R&R	Repair/Replace
RSI	Reusable Surface Insulation
RTOMI	Repetitive Task Operations and Maintenance Instruction
RTS	Remote Tracking System
RTV	Room Temperature Vulcanizing
R&T	Research and Technology
RU	Remote Unit
S	Sulphur
SAFT	Semi-Automatic Flight Line Tester
SAT	Satellite
S&A	Safe and Arm
SB	Space Based
SBS	Space Based System
SBSS	Space Based Space Surveillance (System)
S/C	Spacecraft
SCAPE	Self-Contained Atmospheric Protective Ensemble
SDI	Space Defense Initiative
SDIO	Space Defense Initiative Office/Organization
SDV	Shuttle Derived Vehicle
SiC	Silicon Carbine
SIP	Standard Interface Panel; Strain Isolation Pad
SIT	System Integrated Test
SLSOC	Simplified Launch System Operational Criteria
SM	Support Module
SMA	Shape-Memory Alloy
SMCH	Standard Mission Cable Harness
SME	Shape Memory Effect
SOA	State-of-Art
SOC	Satellite Operations Center
SOPC	Shuttle Operations Planning Center
SOW	Statement of Work
SPACECOM	Space Command
SPADOC	Space Defense Operations Center
SPC	Shuttle Processing Contractor (Lockheed)
SPIDPO	Shuttle Payload Integration and Development Program Office (JSC)
SPDMS	Shuttle Processing Data Management System
SPI	Standard Practice Instructions
SRB, SRBs	Solid Rocket Booster(s)
SRM, SRMs	Solid Rocket Motor(s)
SRSS	Shuttle Range Safety System
SS	Space Station
SSME	Space Shuttle Main Engine(s)
SSMEC	Space Shuttle Main Engine Controller
SSSF	SRB Segment Storage Facility
SSTO	Single Stage to Orbit
ST	Space Telescope
STA,STAS	Space Transportation Architecture (Study)
STC	Satellite Test Center
STE	Systems Test and Evaluation or Special Test Equipment
STS	Space Transportation System; Shuttle Transportation System

ACRONYMS and ABBREVIATIONS
(Continued)

STS II	Space Transportation System II
SV	Space Vehicle
S\W,(SW)	Software
T-III	Titan III
TACAN	Tactical Navigation
TARS	Turnaround and Reconfiguration Simulation
TAV	Transatmospheric Vehicle
TBD	To be Determined/Defined
T&C/O	Test and Checkout
TDAS	Tracking and Data Acquisition Satellite
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TE	Test Equipment
Tempest	Electromagnetic emission suppression for security purposes
TIS	Technology Identification Sheet
TM	Telemetry
TP	Test Point; Test Plan
T-0	Liftoff Time
TOs	Transfer Orbit Stage
TPS	Thermal Protection System; Test Preparation Test
TRAJ	Trajectory
TS	Transportation System
T/S	Test Setup
TSM	Tail Service Mast
T&CN	Telemetry & Communication Network
TTL	Transistor/Transistor Logic
TVC	Thrust Vector Control
UART	Universal Asynchonous Transistor
UDMH	Unsymmetrical Dimethylhydrazine
UDS	Universal Documentation System
UEXCV	Unmanned Expendable Cargo Vehicle
UFRCV	Unmanned Fully Reusable Cargo Vehicle
UFRGB	Unmanned Fully Reusable Ground Based-OTV
UFRSB	Unmanned Fully Reusable Space Based-OTV
UHF	Ultra High Frequency
ULCE	Unified Life Cycle Engineering
ULV	Unmanned Launch Vehicle
UPRCV	Unmanned Partially Reusable Cargo Vehicle(s)
UPRCV(R)	Unmanned Partially Reusable Cargo Vehicle with Return
UPXCV	Unmanned Partially Expendable Cargo Vehicle
UMB	Umbilical
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
VC1	Visual Clean 1 (standard)
VC1A	Visual Clean 1A (sensitive)
VC2	Visual Clean 2 (highly sensitive)
VHF	Very High Frequency
VHMS	Vehicle Health Monitoring System
VHSIC	Very High Speed Integrated Circuit
VIB	Vertical Integration Building
VIF	Vertical Integration Facility
VLSI	Very Large Scale Integration
VPF	Vertical Processing Facility

ACRONYMS and ABBREVIATIONS
(Continued)

WAD	Work Authorization Document
WBS	Work Breakdown Structure
WEM	Water Electrolysis Module
WCCS	Window Cavity Conditioning System
WSMC	Western Space and Missile Center
WCS	Waste Conditioning System
WSB	Water Spray Boiler
WTR	Western Test Range
XTKB	Expanded Technology Knowledge Base

1.0 INTRODUCTION

This Handbook is intended to be a useful tool for all Space Program Management, System Engineers, and Designers. It is a checklist aid in reducing Life Cycle Costs (LCC). SOCH has resulted from a one-year study of Shuttle Program operational problems. This volume presents, in a checklist format, the lessons learned as derived from documentation of problems from Shuttle and other programs.

Extrapolation using actuals from FY-85 Space Shuttle Program (8 launches), shows total Operations Cost will exceed 73% of the Life Cycle Cost while Design and Manufacturing were less than 27% (based on '85$). This is an exorbitant cost for Operations which drives the LCC for one 100-flight Orbiter to $33.9 billion in 1985 dollars. Our best experience to date was FY-85 where Cost/lb in LEO exceeded $5000. Obviously, in future worldwide price competition, the "business as usual" approach will be suicidal for our Space programs.

What is the solution? **DRIVE LCC DOWN DRASTICALLY!** (Order of Magnitude)

How? Put more effort (dollars) up-front in the early design phases to provide for operations efficiencies. These dollars will be recovered many times over.

How? Convince management, congress, and the administration that they may expect exorbitant life cycle costs if funding provisions are not made up-front for operational efficiencies -- both vehicle and facilities.

Then: Use this manual as a starting point and handy checklist for things that must be considered to lower operational costs. If you find only one new item applicable to your work -- it'll be well worth the effort expended in perusing this handbook.

GOOD LUCK!

USE OF THIS HANDBOOK IS RECOMMENDED --

FOR		BY
DESIGN CONCEPTS	-->	DESIGNERS
INITIAL DESIGN	-->	DESIGNERS
DESIGN REVIEWS	-->	PROJECT MANAGERS
MANAGEMENT REVIEWS	-->	PROGRAM MANAGERS
LIFE CYCLE COST REVIEWS	-->	HQ STAFF
		CONGRESSIONAL STAFF

NOTE: The "Circa 2000 Operations Requirements for an Orbital Access System" eliminates the necessity for many of the cost-driver workaround solutions described in this SOCH. The Circa 2000 concept is a separate product of this study which incorporates the deletion of STS cost drivers into an integrated concept. Documentation of this concept is available upon request; contact Study Manager, Art Scholz, (407) 867-2334.

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2.0 PROBLEM AVOIDANCE FOR PROGRAM MANAGEMENT

NOTE: This Section provides a short checklist of the top level management lessons learned from the Shuttle program. It also includes short discussions of the problems, solutions, and examples from the topics listed above. It should be a valuable tool for asking the "right" questions.

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2.1 TOP MANAGEMENT RULES CHECKLIST

PROGRAM: ______________________
MANAGER: ______________________
ORGANIZATION/DESIGN BUILD TEAM: ______________

	APPLICABLE Y/N	REMARKS
1. Life Cycle Cost is the driver of the future — to ignore this is suicidal for any program.		
2. In selling programs, emphasize Life Cycle Cost, not startup costs (particularly in dealing with the Executive Branch and Congress).		
3. The top design priority must be Life Cycle Cost.		
4. Integrate knowledge of all organizations into the original vehicle design through the use of Design/Build teams.		
5. A birth-to-death cost-effective program can only be accomplished with totally integrated data systems (Unified Life Cycle Engineering or ULCE).		
6. Standardization & Commonality are only effective when implemented from the top down.		
7. Design the Support — don't support the design.		
8. Revitalize our total approach to Space Systems development by: Incremental approaches; skunkworks; simplified system specs; and commercial type approaches.		
9. New facilities are probably more cost effective (from an operational life cycle cost standpoint) than forced modification of obsolete facilities from other programs.		
10. Multi-year procurement lowers cost significantly.		
11. The program objectives should determine the organization — not vice-versa.		
12. NASA element managers must be primarily accountable to the overall program manager rather than Center management.		
13. Robustness is an operational design requirement.		
14. Lack of discipline must be overcome by a Deming-type total quality program.		
15. Vehicle Modifications at the launch site must be under the schedule and fiscal control of Launch Operations.		
16. Provide adequate operational spares and make cannibalization a no-no.		
17. For cost-effective manned operations, the "Crew-in-Command" concept must be given.		

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2.1 TOP MANAGEMENT RULES CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
18. Key personnel shortages during extended critical operations can be solved by automating labor-intensive operations.		
19. Minimize the number of boards and reviews, particularly for non-critical documents and changes. Assign more responsibility to line management.		
20. Reduce the duplication of parallel government and contractor organizations.		
21. Minimize the number of meetings, particularly those with large numbers of people.		
22. Enforce elimination of duplicate or unnecessary paper-work, forms, work authorization documents, etc.		
23. Assure establishment of operations teams, comparable to design/build teams, to develop streamline, workable procedures.		
24. Assure a complete review of NASA and MIL Standards, based on life cycle cost analyses.		
25. Assure training of managers to manage, particularly those promoted through the ranks with no formal management training.		
26. Insist on realistic schedules and goals for organizations and systems responsibilities.		
27. Recognize potential mission failure as a reality and develop plans ahead of time to avoid panic and maintain control of the program's destiny.		

2.2 LEADERSHIP

Management Notes

Problem

* Lack of strong leadership at the very top of the Space Agency imperils the ability of the U.S. to regain international leadership.

Solution

* A strong leader to muster and corral NASA's resources to realistically plan and personally present the programs, benefits, and true costs to Congress and the President. This leader should provide stature, leadership, and integrity for Space programs which Americans and Congress will admire and follow. To quote the current NASA Administrator, 10/20/87, "but quite frankly, I think they need a younger, a more ambitious, a more energetic leader."

2.3 MANAGEMENT

Problem

* Old style bureaucratic management has proven to be labor intensive and inefficient.

Solution

* Computerized databases can eliminate need for many middle managers who now only gather and provide information for top management decisions. This will allow top managers who know how to effectively use computer tools to obtain data that is unfiltered and unbiased by middle management protecting their turf. Simply computerizing the bureaucracy must be avoided, however.

* Management culture must change to a more participative management style (a la Deming—see Appendix 6.2) without wasteful departmental barriers, self-propagating rice bowls or self-eating cantaloupes. This must take place both in NASA and Contractor ranks.

* With a high percentage of managers in NASA and Contractors approaching retirement, there is an unusual opportunity to accomplish the change. Care must be taken not to replace these retiring managers with their lookalike proteges or nothing will be gained. Selection of new managers should be based on their ability to make imaginative use of the latest management technology and who are not ingrained with a parochial viewpoint.

* The individual program objectives should determine the organization requirement — not vice-versa.

2.3 MANAGEMENT (CONT.)

Management Notes

Example

* In maturing over the past twenty-five years, aerospace management, both in and out of government, have succumbed to bureaucratic operations whereby consideration of any management or technical problem includes how will it affect the "status quo". If the effect is negative in any way, the answers are skewed making it difficult for top management to make cost effective decisions. Top management also suffers from biased decisions made to accommodate their "status quo".

* The NASA reorganization, in response to the Presidential Commission report on the Challenger accident, did not accomplish the objectives. With few exceptions, organization boxes and people were reshuffled to preserve the "status quo".

2.4 ORGANIZATION

Problem

* As a result of compartmentalized organization responsibilities, past vehicle designs have not fully utilized and integrated the knowledge and experience of specialists in functional organizations.

Solution

* Management must adopt design/build team concepts. This will provide an adequate flow of experience and coordination from operational elements to engineering design and test groups during the definition and development stage.

* Individual program requirements should determine its organizational structure — not vice-versa.

Example

* The sequence of hardware development whereby the hardware designer completes his design (without input from manufacturing, purchasing, operations, etc.) and "throws it over the fence" for the other organizations to do the best they can in producing and operating the hardware in a cost-effective way has led to life cycle costs an order-of-magnitude higher than necessary.

2.5 INDEPENDENT CENTERS

Problem

* Operation of NASA Centers independent of Program direction. Element managers are more accountable to their Center management than to the Program management.

* Center isolation — Centers do not freely or systematically communicate problems to HQ or other Centers.

Solution

* Centralized program management at HQ level controlling funding and work authority. Program work at the Centers should be placed clearly under the Program Manager's authority.

Example

* From the Presidential Commission Report on Challenger — "The Shuttle program management structure should be reviewed. The project managers for the various elements of the Shuttle program felt more accountable to their Center management than to the Shuttle program organization. Shuttle element funding, work package definition and vital program information frequently bypass the National STS (Shuttle) Program Manager. A redefinition of the Program Manager's responsibility is essential. This redefinition should give the Program Manager the Requisite authority for all ongoing STS operations. Program funding and all Shuttle program work at the Centers should be placed clearly under the Program Manager's authority."

2.6 LIFE CYCLE COSTS

Problem

* Operations Cost for the current Shuttle design has proven to be exorbitant. For FY-85, it totaled $2189.4M for 8 flights or $274M/flight:

SRB	$464.2M	Flight Ops	$345.3M
ET	415.8M	Orbiter Hdwre	162.6M
Launch Ops	347.5M	Crew Equip	36.3M
Propellants	30.3M	SSME	51.6M
GSE	24.1M	Contract Adm	17.1M

	Subtotal	$1894.8M
Plus	Network Support	$ 20.4M
	R & PM	274.2M
FY-85 Total Cost		$2189.4M (in '85 dollars)

* Minimizing up-front program costs multiplies life cycle costs.

Solution

* Prepare thorough and realistic life cycle cost analysis for Congress. Emphasize life cycle costs — not start-up costs.

Management Notes

Example

* For Space Station FY-88 Congressional Budget Hearings, NASA was still quoting $100M/flight Shuttle costs which is based on an unrealistic 24 flights/year. This plays down operational costs and the effort that should be made, during the design concept and design phases, to design for lower operational costs both for Space Station and future Launch Vehicles.

2.7 COST DATA

Problem

* Cost data are presented to Congress in many different formats which makes it almost impossible for direct comparisons.

Solution

* Congressional Budget Office should develop standard formats for Space Program budgets with fixed definitions so that consistent comparisons can be directly made. Emphasis should be on Life Cycle Costs.

Example

* What is the cost of a Shuttle flight? $28M, $42M, $76M, $100M, $106M, $150M, $258M, $273M, or $?. The answer depends on many factors. How many flights? full costs? marginal costs? short-run? long-run? fixed costs included? amortization of facilities? amortization of vehicles? amortization of GSE? competitive pricing? expendables included? refurbishment? NASA overhead? Flight Operations? Range support? emergency landing sites? etc., etc.? What year $$?

2.8 REVITALIZATION

Problem

* The Life Cycle Cost of government Space Programs (from concept through the operational life) is exorbitant and wasteful. The actual cost often exceeds the early estimates by as much as an order of magnitude.

Solution

* Revitalize our approach to Space Systems development by:

  + Implement incremental development approaches.
  + Encouraging or mandating "skunk works" type development teams.
  + Simplifying system specifications.
  + Fostering commercial-type approaches to military systems development.

Management Notes

All of the above will tend to result in less costly development programs which will allow both government and contractors to behave more like commercial entities. — Implementation requires culture changes, not just new regulations or reviews — difficult, but can we afford not to try?

Example

* The Shuttle Program, which has done none of the above, has progressed costwise to greater than an order-of-magnitude higher than initially estimated.

	1972 Estimate (1972$/1985$)	1985 Actual (1985 $)
Cost per Flight	$10.4M/29.3M	$273 M
Cost per Pound (in LEO)	$160/474	$5484

2.9 VEHICLE/GSE MODIFICATIONS

Problem

* Design agencies force non-mandatory modifications on KSC by using a mandatory designation with frequent schedule and cost impact.

Solution

* Enforce tight definition of mandatory mods through HQ program control and/or allow Ground Operations to charge back modification costs to the responsible Design Agencies.

  . Modifications at the launch site must be under the schedule and fiscal control of Ground Operations management.

Example

* Mandatory mods often get deferred flight-after-flight if they would seriously impact the launch schedule, thus proving that they are highly desirable — not mandatory.

2.10 TRAINING/CERTIFICATION/DISCIPLINE

Problem

* The results of the Challenger (51-L) investigation by NASA and the Presidential Commission generally showed that while adequate procedures existed for all aspects of vehicle processing — there were numerous cases of inadequate training of personnel in the use of these procedures, and inadequate management discipline in assuring personnel compliance with these existing procedures.

Management Notes

Solution

* Adequate management analysis and planning to determine soft areas where procedures are not followed; training instituted to assure understanding; certification established to identify up-to-date understanding of critical procedures; and management enforcement (with teeth) to assure the necessary discipline.

Example

* From the 51-L Findings, "of approximately 5000 documents evaluated, a very large percentage were found to be in correctly executed. The discrepancies are generally minor in nature such as incorrect signatures, missing signatures, lack of QC, incomplete for closure, etc. However, these discrepancies point to a problem involving lack of discipline and education on procedures and requirements. We need to initiate an across -the-board training program to educate personnel at all levels on WAD preparations, processing, verification, and closure. The SPI (Standard Practice Instructions), the guide for preparing and performing paperwork, needs to be reevaluated, ungraded if necessary, then enforced. Attention to detail must be reemphasized."

* From the 51-L Findings, main propulsion review team, "Usage of test and checkout equipment and techniques training of engineering and technician personnel in the operation of test equipment is critical to the operational efficiency and safety of vehicle and GSE performance. Mandatory training should be required in the use of equipment and the performance of critical skills.

2.11 QUALITY ASSURANCE

Problem

* Quality Assurance places emphasis on inspection. As a result of the Challenger loss and the Presidential Commission Report, Program management has amplified this problem by increased manpower and efforts to inspect quality into the product. American industry, led by Japan's implementation of Deming's methods, is beginning to understand that inspection is not only costly, but also ineffective.

* Lack of discipline in following established procedure; lack of appreciation for the serious consequence potential.

Management Notes

Solution

* New systems design should place emphasis on computerized, self-check verification for electrical systems and require minimal inspection for mechanical and structural systems.

  . Management and workers must be be trained and led into a total quality program (a la Deming - see Appendix 6.2). The Deming approach is not to automate quality verification, but instead to build quality into the product and promote quality workmanship to eliminate the need for constant inspection. This would require a major change in culture as well as MIL-standards but needs to be done.

2.12 ROBUSTNESS VERSUS OVERDESIGN

Problem

* Lack of robustness has led to increased Operations and Life Cycle Costs.

Solution

* Design should allow for consistent operation well below design limits. This will extend operational life, minimize maintenance, and allow for efficient mission expansion.

Example

* SSME design is marginal rather than robust. SSME's operate at 104% of nominal at during flight. This significantly decreases reliability and increases maintenance and overhaul time and cost.

2.13 DATABASE INTERCHANGE STRUCTURE

Problem

* No common database interchange structure exists for design criteria, design data, manufacturing data, reliability data, QA data trails and closeout, operations & maintenance procedures, requirements satisfaction. This has led to gross duplication, omissions, inefficiencies, and errors.

2.13 DATABASE INTERCHANGE STRUCTURE

Management Notes

Solution

* Implement Unified Life Cycle Engineering (ULCE) system to provide birth-to-death unified data interchange, and enforce total use of MIL-STD-1840A throughout all system development and operational phases.

  . Provide for computerized approval/concurrence control of requirements, procedures, and anomaly closeouts as part of ULCE; also provide for risk management, configuration control, mission/range support, flight readiness reviews, resolution of in-flight anomalies, etc.

Example

* There is little or no data interchange capability between current STS design and operations databases.

2.14 LAUNCH AND MISSION CONTROL CENTERS

* STS design requires large numbers of support personnel in Launch and Mission Control Centers.

* Flight crews do not have adequate input into design and operations criteria.

* During Shuttle definition and development, there was an attempt to place the crew in the operational command loop; however, the total Mission Control Center concept won out.

Solution

* With future manned vehicle design headed towards on-board, "Crew-in-Command", autonomy to lower Operational Costs, flight crew members should be included in design/build teams for hardware and software systems involving: Preflight Systems Check; Countdown; Ascent Flight Control; Orbit Insertion; Orbit Management System/Consumables Management (including Anomalies); Mission Command; Mission System Management and Operation; Orbit Maneuver; Mission Replanning; Earth Return Energy Management and Flight Control.

2.15 KEY PERSONNEL SHORTAGES

Problem

* Labor intensive operations cause key personnel shortages during extended critical launch operations.

Management Notes

* Unreasonable overtime requirements as a safety issue is underscored by the variety of accidents and incidents associated with Shuttle processing in recent years. This extensive overtime is a tradeoff between the desire keep on duty those personnel with the greatest expertise and the need to guard against the undesirable effects of fatigue.

* Planning for surge capability needs to consider the fact that organizations are sized so that overtime is a part of normal operations. This means that to surge by a factor of 1.5 to 2.0 is not possible. New personnel without launch operations experience will be hired with an impact on both quality and reliability.

Solution

* Comprehensive test automation to reduce requirement for key personnel and the extended time requirements for testing.

Example

* One potentially catastrophic human error occurred 4 minutes, 55 seconds before the scheduled launch of 61-C on 1/6/86. according to a LSOC incident report, 18,000# of LOX were inadvertently drained from the ET due to operator error. Fortunately, the LOX flow dropped the main engine inlet temp below the acceptable limit causing a launch hold, but only 31 seconds before liftoff. The investigation revealed that console operators in the LCC had misinterpreted system messages resulting from a failed microswitch on a replenishment valve; the operators had been on duty at the console for eleven hours during the third day of working 12-hour night (8pm to 8am) shifts.

2.16 DESIGN PRIORITIES

Problem

* Design Priority is a compromise between performance, reliability, maintainability, weight, space restrictions, safety, cost, schedule, etc. Up-front costs and performance have had the top priority.

* Operational and logistics inefficiencies result from lack of priority and lack of knowledge of operational requirements by those responsible during the design phases.

Solution

* Program management must re-prioritize these factors in the future to recognize Life Cycle Costs as the driving factor and the significance of Operations Costs as the major driver.

* Simplicity in design can lead to the most efficient, flexible, reliable, and cost effective solutions and needs to be stressed as one of the highest design priorities.

* Beginning with the conceptual design phase, specific emphasis should be placed on accessibilty for maintenance, test automation, standardization of parts, modularity, redundancy, and asset interchangeability.

* The design/build team should have strong representation from the logistics/maintainability areas with the power to monitor and make changes to design, contracts, development, and verification efforts.

Example

* The current Shuttle vehicle could never be an operational vehicle without major block modifications to incorporate maintainability provisions in each system. Lack of self-test capability, commonality, and accessability are typical of its shortcomings.

2.17 CANNIBALIZATION

Problem

* Spare parts provisioning is yet another illustration that the Shuttle Program was not prepared for an operational schedule. The conscious decision was made to postpone spare parts procurements in favor of budget items of perceived higher priority. The policy proved to be shortsighted and has led to the inefficiencies of cannibalization to support the flight rate.

Solution

* Accept the necessary up-front costs of adequate spares provisioning in order to reduce Life Cycle Costs with more efficient operations.

Management Notes

Example

* From the Challenger Presidential Commission Report, "The logistics support for 51-L ground processing was inadequate, since it created a need to remove parts from other orbiters to continue 51-L operations. For 51-L, 45 out of approximately 300 required parts were cannibalized. These parts ranged from bolts to an OMS TVC actuator and a fuel cell. The significance to operations of cannibalization is that it creates (1) significantly increased efforts to accomplish the same work due to multiple installation and retest requirements, (2) schedule disruption due to added work and normally later part availability, and (3) orbiter damage potential due to increased physical activity in the vehicles. These efforts make cannibalization operationally unacceptable."

2.18 COMMONALITY

Problem

* Cost-effective commonality opportunities have not been implemented from the top down.

* Scrapping existing systems to justify and provide funds for new development; i.e., Saturn V and Shuttle.

Solution

* Management must remain vigilant for cost-effective commonality opportunities which can be implemented top-down.

* Use building block growth programs to minimize need for qualification and flight testing. Subsystems and technologies already proven in similar applications should be considered for direct use or modification to enhance cost-effectiveness and reliability.

* Wherever possible, management should elect to design and qualify changes to the highest environments that might be experienced with the next several projected growth changes. Minimal cost is incurred in the over-design that results, and greater confidence is generated for early users because unusually high margins exist. The systems, designed and qualified for future growth, do not then need to be requalified when the next growth change occurs. This prior qualification minimizes the cost of the new change and reduces the magnitude of the unknown risks.

Management Notes

Example

* The Delta Program provides some cost-effective techniques: Building block approach whereby subsystems and technologies already proven by prior use in similar applications were incorporated. Items utilized in various manned & unmanned space programs were tailored to fit current LV requirements. The USAF-developed strap-on motors for Thor were adapted. The NASA Surveyor retro-motor and USAF FW4 motor were used as the Delta 3rd stage. The Apollo LEM descent engine thrust chamber was incorporated into the Delta 2nd stage. These "borrowed" systems keep costs down and maximize reliability.

2.19 PROCUREMENT

Problem

* Single year procurements add significantly to procurement costs.

* Procurement of major subsystems through prime contractors increases subsystem costs. Conversely, prime contracts that specify GFE severely limit prime contractor ability to achieve an overall cost effective design.

* Procurements which provide detailed system/subsystem specifications in place of, or in addition to, end product performance specifications limit the prime contractor's capability to be innovative and cost effective.

Solution

* Use multi-year procurement whenever possible — commit to larger quantities to lower acquisition costs.

* Direct buy of major systems, such as engines, by the government to eliminate multiple fee and G & A, only where it does not limit the prime contractors prerogatives to be innovative and cost effective.

* Program level specifications should be developed only for the top level of end product performance and include profit incentives.

* Make maximum use of commonality.

Example

* The Lunar Orbiter was a highly successful program that used only program level specifications in the procurement.

2.20 FUNDING PEAKS

Problem

* Overlapping vehicle program developments cause unreasonable funding peaks.

Solution

* Force elimination of similar program development by different government departments (i.e., NASA, AIR FORCE).

Example

* Shuttle C and ALS

2.21 MANIFEST CHANGES

Problem

* Downstream manifest changes can saturate facilities and personnel capabilities. The strain on resources can be tremendous.

Solution

* Tight control on manifest changes.

Example

* For short periods of two to three months in mid-1985 and early 1986, Shuttle facilities and personnel were being required to perform at roughly twice the budgeted flight rate. If a change occurs late enough, it will have an impact on the serial processes. In these cases, additional resources will not alleviate the problem, and the effect of the change is absorbed by all downstream processes, and ultimately by the last element in the chain.

* According to Astronaut Henry Hartsfield: "Had we not had the accident, we were going to be up against a wall; STS 61-H .... would have had to average 31 hours in the simulator to accomplish their required training, and STS 61-K would have to average 33 hours. That is ridiculous. For the first time, somebody was going to stand up and say we have got to slip the launch because we are not going to have the crew trained."

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3.0 SYSTEMS ENGINEERING CHECKLISTS

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3.0 SYSTEMS ENGINEERING CHECKLISTS

3.1 Automation
3.2 Autonomy
3.3 Change Control / Configuration Management
3.4 Growth
3.5 Hazardous Operations
3.6 Interfaces
3.7 Maintainability
3.8 Operations Cost
3.9 Payloads/Cargo
3.10 Processing Time Drivers
3.11 Reliability

NOTE: When using these Systems Engineering Checklists, please keep the following in mind:

* All items are not pertinent to every system.
* Some items are contradictory. For example, an item may be applicable to a near-term design but not be desirable for a more advanced design.
* Some items represent better solutions than others.

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3.1 AUTOMATION CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Automate to avoid perceptual saturation.		
2. Automate to reduce concurrent tasks.		
3. Automate tasks on compressed timelines.		
4. Automate to avoid human bandwidth limitations.		
5. Automate routine tasks.		
6. Automate memorization tasks.		
7. Automate sequential and time tasks.		
8. Automate monitoring tasks.		
9. Automate time consuming, boring, or unmotivating tasks.		
10. Automate emergency-prevention devices.		
11. Automate complex mathematical or logical tasks.		
12. Automate complex tasks that must be performed rapidly.		
13. Automate to enhance system reliability.		
14. Automate safety endangering tasks.		
15. Automate systems with consideration to crew acceptance.		
16. Create software capable of decision making and self control.		
17. Provide ground computer problem flagging and resolution instructions.		
18. Design systems to be self supporting (not ground dependent).		
19. Systems should have capability of being powered up/down automatically under software control versus cockpit/panel switches.		
20. Design self-diagnosis into systems which identify system degradation as well as hard failures.		
21. Computer system should be designed for autonomous fault isolation to LRU level.		
22. Automate Time/Cycle flags.		
23. Redundant systems should have built-in self checking capability.		

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3.1 AUTOMATION CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
24. Automatic control limits should be based on measurements of the critical condition, not on an intermediate computation.		
25. Automated monitor and control should be considered for reduction of manhours required for testing and fault isolation. This should not be considered on the basis of bad past experience, but with the latest technology which almost eliminates false alarms.		
26. Use of off-the-shelf equipment limits the amount of automation which can be incorporated into system design.		
27. Design ORU'S with built-in diagnostic capability to facilitate fault isolation.		
28. Consider manual override capability for all automatic control functions to aid checkout and troubleshooting.		
29. Use self-testing LRU's to avoid the requirement of checkout following changeout.		
30. Barcode all LRU's across all GSE and vehicle test equipment to allow automated inventory and configuration control.		
31. To save cost of a high-fidelity mockup at design agency, use ULCE capabilities to assure form, fit, and function prior to installation in flight vehicle.		

3.2 AUTONOMY CHECKLIST

SYSTEM: ____________________
SUBASSEMBLY: ____________________
ENGINEER: ____________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Autonomous functions to be capable of being separately enabled, disabled, or updated under the supervisory control of ground controllers and/or flight crew.		
2. Current sensor data and autonomy-related operational status information should be maintained and made available upon request through memory readout to ground and onboard operators.		
3. An audit trail of pertinent autonomous activities and resultant state changes should be stored and available for readout to ground controllers or flight crew members upon request.		
4. Source of control should be transparent to the user whether from onboard machine autonomy, the flight crew, or ground controllers.		
5. Test validation required for performing maintenance functions should be accomplished in parallel with normal operations on a noninterference basis.		
6. Any nonrecoverable fault associated with autonomous operations should result in a fail-operational and/or fail-safe mode.		
7. Automated fault diagnosis, isolation, and recovery of many deterministic fault conditions should significantly enhance crew safety.		
8. Self-test design features should be incorporated into both the hardware and software of the autonomous system to ensure proper operation even in the presence of internal faults.		
9. Software health and maintenance algorithms should be designed to perform adequate diagnostics and verification prior to issuing warnings and hardware reconfiguration commands so that the occurrence of false alarms and "trial and error" redundant element switching are the exception rather than the rule.		
10. Transient errors such as transducer glitches, bit errors, etc., should be accommodated by the autonomous system design such that they are transparent to the functional operation and configuration.		

	APPLICABLE Y/N	REMARKS
11. Implementation of autonomy design features should not introduce any single-point failures or significantly degrade reliability.		
12. Significant increases in cycling and stress of functional elements resulting in decreased reliability should not be required by autonomy implementation.		
13. There should be a rigorous examination of all fault diagnosis thresholds in the context of the expected and actual mission environment.		
14. The autonomous system design should not effect changes in a state of operation that are not reversible.		
15. The autonomy system design should provide protection from erroneous commands from all human or machine sources.		
16. Systems should have the capability of being powered up/down automatically under software control versus cockpit/panel switches.		
17. "Crew-in-Command" preflight system check.		
18. "Crew-in-Command" ascent flight control.		
19. "Crew-in-Command" orbit insertion.		
20. "Crew-in-Command" orbit management.		
21. "Crew-in-Command system/consumables management (including anomalies).		
22. "Crew-in-Command" mission command.		
23. "Crew-in-Command" mission system mgmt. and operation.		
24. "Crew-in-Command" orbit maneuvers.		
25. "Crew-in-Command" mission replanning.		
26. "Crew-in-Command" earth return energy mgmt. and flight control.		
27. Dependence on the Mission Control Center (MCC) should minimized for ground-based computations and data to support navigation, maneuvering, sortie operations, deorbit & entry targeting, & malfunction diagnosis.		
28. Essential systems should be completely independent of other systems and subsystems.		
29. Design the vehicle with maximum independence of GSE.		
30. Avoid the need to mix User data with vehicle or space station "upkeep" data, thus eliminating the constant need to reallocate link, bandwidth, and areas.		

	APPLICABLE Y/N	REMARKS
31. Provide standalone capability of Range Safety checkout systems.		
32. Individual subroutines, modules and packages should be isolatable and reinstallable with total transparency so algorithms can be corrected, improved, or changed without bulk processing.		
33. Avoid requirements for multiple switching operations to accomplish a single system mode change.		
34. Avoid systems that are tied together so that the failure of one system and the subsequent replacement of parts, require the retest of other systems.		

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3.3 CHANGE CONTROL/ CONFIGURATION MANAGEMENT CHECKLIST

SYSTEM: ______________________________
SUBASSEMBLY: ______________________________
ENGINEER: ______________________________
ORGANIZATION/DESIGN BUILD TEAM: ______________________________

	APPLICABLE Y/N	REMARKS
1. Change control system should be designed for the long term user and not the one-time designer/builder.		
2. There should be a single program code identification or control number for changes.		
3. Modifications at the launch site must be under the control of the Launch Operations organization.		
4. Reference designators should be of a constant format across all program elements (contractors).		
5. Any modification of a contractor or government furnished equipment should be clearly identified on the drawing and the part.		
6. Ensure that all repairable LRU's and their components are identified as such.		
7. Drawing change control and release system should be designed for the long range user and not the one-time designer/builder.		
8. Manufacturing drawings shall be purchased for all assemblies.		
9. Engineering drawings and schematics contain complete systems.		
10. Drawing and part numbering should be logical and sequential using a standardized format and designation.		
11. Any modification of contractor or government-furnished should be clearly identified on the part and drawing.		
12. Enforce a standardized drawing and part number system on all contractor and government furnished equipment.		
13. All drawings must be updated to match final hardware.		
14. Modification of the parts of one contractor by a second contractor should be clearly defined on drawing.		
15. Avoid the vendor-controlled drawing concept when dealing with components.		
16. Provide updated drawing and establish configuration control when modifying old facilities.		

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3.3 CHANGE CONTROL / CONFIGURATION MANAGEMENT CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
17. Maintain configuration control documentation showing current approved location of units.		
18. Do not generate mods on separate drawings, but rather incorporate on basic drawing.		
19. Provide single point listing of configuration documents.		
20. Take care with commonality among software components. Too much commonality can cause problems with future changes and modifications. Tools are needed to trace component links and data exchanges.		
21. Include a logistics representative on the design team to continually address the problems of standardization, ease of maintenance, and accessibility.		
22. Be aware of the potential of flight software over-writing countdown software.		
23. An automated system must be developed to provide an audit trail of changing mission requirements, support capabilities and Range commitments. The Range Universal Documentation System (UDS) and the NASA system must be compatible for data exchange.		
24. A maintainability representative should sit on the change boards with status equal to engineering and financial representatives.		
25. The number of different coordinate systems should be minimized and controlled.		

3.4 GROWTH CHECKLIST

SYSTEM: ______________________

SUBASSEMBLY: ______________________

ENGINEER: ______________________

ORGANIZATION/DESIGN BUILD TEAM: ______________________

	APPLICABLE Y/N	REMARKS
1. Design environment to accommodate commercial and off-the-shelf technology.		
2. Incorporate standard interfaces.		
3. Design for ease of assembly and servicing.		
4. Design for ease of identification and accessiblity.		
5. Design for autonomy of routine deterministic operations.		
6. Design an evolutionary computer system architecture.		
7. Incorporate CAD/CAE for accommodating artificial intelligence and robotics technology.		
8. Increased lift capability is required for: adding autonomous checkout subsystems; increasing redundancy; increasing safety; and containerized payloads.		
9. Modularize for growth and reduced cost.		
10. Design and qualify changes to the highest environments that might be experienced with the next several projected growth changes. Minimal cost is incurred in the overdesign; confidence is generated for early users; and the systems do not require requalification for the next growth. —Overqualify vehicle for future growth—.		

3.5 HAZARDOUS OPERATIONS CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Ordnance operations must be absolutely minimized and preferably eliminated from the processing flow.		
2. Toxic materials should be eliminated or controlled by system containerization to accommodate equipment change-out without evacuation of surrounding area.		
3. Systems must be designed with sufficient safety factors so that personnel access is not restricted when the system is at full flight pressure.		
4. Facility locations for hazardous materials & operations must be such that planned activities do not preclude normal operations in adjacent facilities.		
5. Use commodities that do not require deservicing.		
6. Use leak path self-sealing systems.		
7. Include isolation valves for fluid systems.		
8. Minimize hazardous system interfaces.		
9. Eliminate hazardous material storage requirements.		
10. Provide computer database that shows hazardous operation clearance criteria. List hazardous activity compliance.		
11. Payloads and/or their propulsive stages which require vehicle changes should receive special safety emphasis reviews in addition to the normal configuration change formality.		
13. Dry air rather than inert gas should be the purge medium. Modest decrease in contamination potential does not justify the risk of large-volume inert purges.		
14. Systems designed for emergency action should be simple to operate and have rapid response. Operation, controls, color coding, etc., should all be standardized to allow safe, rapid operation.		
15. Control panels should not be located in major crew traffic routes. If located in heavy traffic area, bump-proof switch guards should be incorporated.		
16. Computer software verification system must be of highest quality to avoid subtle influences and sources of error generated by even small changes on one part of a program on another.		

3.6 INTERFACE CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Enforce common interface mating hardware and interfaces common to all payloads.		
2. Minimize mating functions.		
3. For mating functions, minimize shimming and number of bolts, and assure free access.		
4. Eliminate requirement for closeout latching.		
5. Design interfaces for self-alignment and automate.		
6. Eliminate umbilicals where possible.		
7. Eliminate hardwire data and control links through use of optical links between vehicle and GSE.		
8. Capability for prelaunch verification without umbilicals		
9. If umbilical is absolutely necessary, it should be at base of vehicle with liftoff disconnect.		
10. Payload testing should be entirely offline.		
11. Payloads should be autonomous from launch vehicle.		
12. Minimize multiple diameter stages.		
13. Establish common handling attach point approach for all vehicle segments to eliminate special handling equipment.		
14. There needs to be an audit trail capability established for changing mission requirements, support capabilities, and range commitments.		
15. Provide for Q D filter element inspection at interfaces.		
16. Consider Tempest security requirements.		

3.7 MAINTAINABILITY CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Accessibility must be stressed to ensure capability for on-orbit maintenance.		
2. Protective covers must be used in areas that experience heavy personnel traffic.		
3. Do not require removal of an LRU to access another since this requires retest.		
4. Avoid unique designs just for the purpose of interchangeability.		
5. Fluid lines must be designed with optimum protection. Quick repair patch kits are also required.		
6. Connector designs are required which eliminate bent pins to eliminate orbiter down time from this cause.		
7. Improve maintainability through use of service panels.		
8. Obtain comprehensive vendor maintenance instructions during the production run.		
9. Design such that inaccessible hardware will not require reconfiguration.		
10. Give emphasis to servicing operations in the design of hardware interfaces.		
11. Protective covers should be colored red or marked "fragile" in high traffic areas.		
12. Develop standard procedures across all sub-systems for maintenance and retest.		
13. Provide a defined maintainability design criteria at the inception of the program and a strong design review board to monitor adherence to these criteria.		
14. Standardize the type and location of connectors for ease of maintenance.		
15. Design system to enable fuse changeout or circuit breaker reset without disturbing system integrity.		
16. Include a logistics representative on the design team to continually address the problems of standardization, ease of maintenance, and accessibility.		

	APPLICABLE Y/N	REMARKS
17. Standardize patch cable configuration to prevent unnecessary cable connects/disconnects during vehicle processing.		
18. Long-term space environment with pressurization\de-pressurization of modules may result in fit problems if panels/doors are integral part of structural integrity.		
19. Design self-diagnosis into systems which identifies system degradation as well as hard failures.		
20. Maintenance procedures should be programmed into a database that includes troubleshooting , LRU and retest procedures for all subsystems.		
21. Engineering/drawing change control and release system should be designed to service all users — not just the designer. ULCE is a solution to this problem.		
22. System elements should be centralized in order to facilitate maintenance/troubleshooting/LRU changeout.		
23. Systems must be modularized for rapid replacement with simple interfaces between replaceable modules.		
24. Rapid changeout capability for LRU's.		
25. Post changeout LRU verifications should be minimized or eliminated.		
26. Avoid unique parts requiring unique skills.		
27. Common connectors and good access redundancy on power systems are required.		
28. Design of operation controls and displays should be standardized.		
29. Stress commonality of components throughout systems.		
30. LRU changeout should not compromise the integrity of systems of which it is not a part.		
31. Design system to enable printed circuit board changeout without removing ORU from system in order to minimize retest.		
32. Utilize deadface switches that will allow ORU changeout without extensive power-downs.		
33. Cycle spares through vehicle mockup to assure full compatibility.		

3.8 OPERATIONS CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM ____________________

	APPLICABLE Y/N	REMARKS
1. Quick-change subsystems and main engines if possible with 100% accessibility to critical components.		
2. Standardized interfaces and parts with priority to high reliability, standard, off-the-shelf components.		
3. Component replacement rather repair in on-line integration flow.		
4. Standardized payload canister/shroud interfaces to core stage with automated/robotic shroud connections and no shroud separation pyrotechnics.		
5. Reduce number of large element attachments.		
6. Design simple attach mechanisms not requiring precise alignment.		
7. Develop self-alignment and auto mate/demate interfaces.		
8. Design for rapid mount and connection.		
9. Group LRU's together in readily accessible compartments.		
10. Develop high reliability LRU's to minimize redundancy.		
11. All weather launch and recovery capability is required to shorten ground processing times.		
12. Develop auto mate/demate with remote integrity/monitor and self-check capability.		
13. Eliminate T-0 disconnects; design for all disconnects to be removed and secured T-5min or earlier.		
14. Eliminate the need for hands-on inspection of umbilical connection.		
15. Design umbilical interfaces at the base of the vehicle and eliminate special access equipment.		
16. Self-supporting structure without internal pressurization during transport and erection.		
17. Single point power interface to core stage for all vehicle to reduce hazardous operations.		
18. Integrated or plug-in GSE automated final checkout & launch system.		

	APPLICABLE Y/N	
19. Improved adverse weather capability: minimize impact of weather and other launch constraints including fog, wind shear, thermal inversions, temperature, humidity, downrange intrusion, etc.		
20. Minimize downrange travel of engine recovery module.		
21. Non-toxic liquid propellants.		
22. Minimize number of propellants used for stages and other applications.		
23. Design for automated leak detection.		
24. Develop leak self-healing technology.		
25. Minimize fluid interfaces and potential leak paths.		
26. Develop actuators that do not require testing, servicing, and flight preps.		
27. Utilize propulsion systems that do not require offload and servicing of propellant systems after each flight.		
28. Employ propulsion/propellant systems that do not require startup prior to final launch sequence.		
29. Eliminate use of solid propellants and pyrotechnic devices to reduce hazardous operations. Replace on-board Range Safety ordnance with ground-based SDI-type destruct system.		
30. A system must be devised to identify orbiter/payload interface problems/delays before they become a field constraint.		
31. Fund maintainability/accessibility up-front to significantly reduce later operations costs.		
32. Recovery of reusable hardware at the launch site rather than remote land or sea location provides a savings in ground operations cost.		
33. Provide sufficient APU tank capacities to allow for launch delays.		

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3.9 PAYLOADS/CARGO CHECKLIST

SYSTEM: ____________________
SUBASSEMBLY: ____________________
ENGINEER: ____________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Wherever possible, provide self-sufficient payloads to minimize interfaces with vehicle.		
2. Minimize the number of interface connectors.		
3. Incorporate standard interface formatting into upper stage or launch vehicle.		
4. Modularize for growth and reduced cost.		
5. Place critical or low mean-time-to-failure in areas which are readily accessible.		
6. Encapsulate or use bags and local purges to reduce demands on facilities.		
7. Design payloads to be compatible with all launch vehicles within an architecture.		
8. Develop payload design standards.		
9. Enforce common interface mating hardware and interfaces common to all payloads.		
10. Rigorous controls should be placed on cargo manifest changes to limit the pressures such changes exert on schedules and crew training.		
11. Payloads and/or their propulsive stages which require vehicle changes should receive special safety emphasis reviews in addition to the normal configuration change formality.		
12. Avoid complex and critical payloads which require vehicle modification.		
13. Standardize electrical and attach point fittings/devices		
14. Eliminate or minimize active heating rejection requirements while in the payload bay.		
15. Avoid special attitude and thermal constraints.		
16. Segregate vehicle/payload communications equipment.		
17. Use separate computer for payload interface.		
18. Provide self-contained power and cooling capability for payloads.		
19. Use generic documentation to streamline integration process.		

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3.9 PAYLOADS/CARGO CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
20. Accommodations for payloads should be designed for ease of installation, removal, and interface verification.		
21. Simplify, minimize, and standardize interface requirements between payloads and launch vehicles.		
22. Simplify mission-to-mission cargo bay reconfiguration requirements.		
23. Provide spacecraft/payload designers with standard hardware interface definition and standard operations procedures early in the design cycle.		
24. Standardize operations for inclination and altitude.		
25. Standardize flight phases: ascent/proximity operations/deployment/spacecraft handling/RMS-Spacecraft separation /thermal profiles/rendezvous/entry.		
26. Standardize spacecraft deployment systems & procedures.		
27. Standardize mission requirements documentation.		
28. Standardize payload hardware/operations interface design requirements for: power, cooling, command, data, integration hardware, RMS, docking mechanisms, and crew interfaces.		
29. Standardize spacecraft servicing functions, interfaces, and procedures.		
30. Provide minimum and standard flight and ground crew simulation and training based on: standard flight profiles/phases; standard spacecraft interfaces and operations procedures.		
31. Provide cargo mix flexibility by standard payload interfaces, operations procedures, and accommodation allocation.		
32. Standardize GSE and ASE at all locations.		
33. Standardize payload consumables.		
34. Use dedicated P/L telemetry system to reduce impact on vehicle T/M software and inflight configuration.		
35. P/L software separate and modularized to avoid revalidation of vehicle software.		
36. Common P/L command & data bus for multiple payloads to reduce overall support.		

	APPLICABLE Y/N	REMARKS
37. Provide dedicated P/L support avionics to reduce LV reconfiguration and verification.		
38. Provide electrical and fluid interface plates for payloads.		
39. Minimum interfaces between payload and vehicle will enable clearer boundaries of responsibility.		

3.10 PROCESSING TIME DRIVERS CKLIST

SYSTEM: ______________________________
SUBASSEMBLY: ______________________________
ENGINEER: ______________________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. STANDARD — Test Requirements		
2. STANDARD — Maintenance Requirements		
3. STANDARD — PLB Deconfiguration/Reconfiguration Requirements		
4. STANDARD — PL/Experiment Offload Requirements		
5. STANDARD — PLB Cleanliness Requirements		
6. NON-STANDARD — Vehicle Modification Requirements		
7. NON-STANDARD — Deferred Work Requirements		
8. NON-STANDARD — Time/Cycle Maintenance Requirements		
9. NON-STANDARD — In-Flight Anomaly Resolution Reqmts.		
10. NON-STANDARD — In-Processing Anomaly Resolution Reqmts		
11. NON-STANDARD — Structural Inspection Requirements & Resultant Findings Resolution		
12. NON-STANDARD — Mission Performance R/R Requirements		
13. NON-STANDARD — Kit Installation/Removal Requirements		
14. OTHER — Spares Availability/Cannibalization Reqmts.		
15. OTHER — Electrical Connector Retest Requirements		
16. OTHER — In-Flow Change Requirements		
17. OTHER — Real Time (PRCBD) Work Requirements		
18. OTHER — Anomaly Corrective Action Retest Reqmts.		
19. OTHER — Safety Requirements/Constraints		
20. OTHER — Facility Anomaly Resolution & Outages		
21. OTHER — Weather Constraints (Pad Operations)		
22. OTHER — Late Payload Installation Requirements		
23. OTHER — Late Payload Bay Access Requirements		

3.11 RELIABILITY CHECKLIST

SYSTEM: ____________________
SUBASSEMBLY: ____________________
ENGINEER: ____________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Systems and components must be simplified and ruggedized to reduce failure modes.		
2. Performance margins must be increased & more extensive qualification testing performed to increase MIBF.		
3. Designs must include status monitoring features so that system health can be easily & quickly determined.		
4. Performance must be completely mapped as a function of time-in-service so that maintenance and replacement can be planned to minimize operational impacts.		
5. STS experience indicates need for a continuous ground hot fire test program with multiple engines that demonstrate operational time far in excess of fleet leader.		
6. Rigid mounting of vertical gyros in high vibration locations has led to failures - Shock mount.		
7. Provide drainage at lowest point in hollow structures to prevent corrosion or freezing stress.		
8. Launch vehicles must be designed with very large performance margins and system redundancy:		
. To allow operation well within design margins.		
. To ensure mission completion despite hardware failure.		
. To require less pre-launch testing.		

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4.0 TECHNOLOGY CHECKLISTS

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4.0 T E C H N O L O G Y   C H E C K L I S T S

NOTE: When using these New Technology Checklists, please keep the following in mind:

* The cryptic technology description is intended only as a clue that this "technology" is, at the least, being considered for development. There are some duplicate technology descriptions with different terminology.

* The risk index column should be completed based on the definitions given at the beginning of this Section and your own technology and status investigation.

* Technology that increases complexity or hazards increases Life Cycle Cost.

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4.1 TECHNOLOGY RISK INDEX SCALE

Index **Description**

OFF-THE-SHELF

1. Off the shelf; little or no modification to that which is existing.

2. Off-the-shelf design; each item is fabricated to individual end specification.

STATE-OF-ART (SOA) WITH PROVEN SOLUTION

3. Known materials, process, methods, and design techniques; no extension to SOA; few problems.

4. Materials, processes, and methods are presently employed but not to such an extent or magnitude; may be unknown problems in design.

EXTENSION TO THE SOA WHICH REQUIRES DEVELOPMENT

5. Materials, processes, or methods have been developed but have not been used in such an application; there are some unknown problems in design.

6. Apparent solution based upon analysis and physical investigations such as pilot models, simple simulations, etc.; additional development is required to confirm; many associated problems, many not known.

BEYOND SOA

7. Apparent theoretical or empirical solution; no actual physical confirmation of the solution; would require extensive development; likely many associated problems, few identified.

8. Solution looks probable but can only be found with extensive research and development.

9. No reason to doubt a solution can be found if enough time and and money are available.

10. Unknown materials, processes, and methods; at this time, there is no indication of a solution to the problem.

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4.2 AEROTHERMODYNAMICS

	LV	ORB	FACIL.	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* Large Scale Parafoil - Precision Recovery	X						
* Aerodynamic Configuration/Aerothermodynamics (Flow Fluid Analysis, Experimental Database, Ascent/Entry Environment, Control Configured Design)	X	X					

4.3 AUTOMATION & ROBOTICS

4.3.1 GENERAL

	LV	ORB	FACIL.	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* Autonomous, On-board Mission Control Expert	X	X			X	X	
* Launch Control Expert				X			
* Vehicle Ground Expert Processing Planner				X			
* Automated Malfunction Procedure & Safing				X		X	
* Automated Self-Checkout	X	X		X	X	X	
* Software Production & Maintenance Methods	X	X	X	X	X	X	
* Software Engineering Environment	X	X	X	X	X	X	
* Software Languages	X	X		X	X	X	
* Rapid Prototyping	X	X		X		X	
* AI in Software Engineering	X	X		X	X	X	
* Software Metrics & Measurement	X	X				X	
* Large Capacity Storage - Optical Disks		X		X	X	X	
* Robotic Macroprocessing		X		X	X	X	
* Smart Sensors for Robotics & Automation	X	X	X	X		X	
* Computer-aided Manufacturing	X	X		X		X	
* Auto Assemble & Test			X	X		X	
* Self-Diagnostics/Self Test	X	X		X	X	X	
* Space-Basing	X	X	X			X	
* Optical Computing	X	X			X	X	
* Large-scale Robotics for Segment Handling, Stacking, and Mating	X			X			
* Payload Handling Robotics		X		X		X	

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4.3.1 GENERAL (CONT.)

	LV	ORB	FACIL	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* Robotics for Assembly, Disconnects, and Umbilicals			X	X		X	
* Hypergolic Load/Unload			X	X			
* Cryogenic Load/Unload			X	X			
* MLP and Tower Support			X	X			
* Teleoperated Robotic Scanning for Postflight Damage Assessment				X		X	
4.3.2 ANOMALY RESOLUTION EXPERT SYSTEMS							
* Computer-Aided Preliminary Design for Testability (CAPDT)	X	X		X		X	
* Smart Built-In Test (Smart BIT)	X	X		X		X	
* Smart System Integrated Test (Smart SIT)	X	X		X		X	
* Maintenance Expert - Box (ME Box)	X	X		X		X	
* Maintenance Expert - System (ME System)	X	X		X		X	
* Maintenance Expert - Smart (ME Smart)	X	X		X		X	
* Automatic Test Program Generation (ATPG)	X	X		X		X	
* Smart Bench	X	X		X		X	
4.3.3 MISSION CONTROL EXPERT SYSTEMS							
* Flight Design(Trajectory, on-orbit, contingency planning)					X		
* Vehicle/Cargo Flight Software Design & Integration					X		
* Product Integration Management					X		
* Configuration for Software & Documentation Products & Distribution					X		
* Software Integration & Testing with Diagnostic Analysis	X	X		X	X		
* Interface Testing	X	X		X	X		
* Test & Diagnostics for Integration Verification	X	X		X	X		
* Scheduling Flight Controller, Crew, & Customer Training					X		

4.3.3 MISSION CONTROL EXPERT EXPERT SYSTEMS (CONT'D)	LV	ORB	FACIL	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* Integral and Part Tasks Trainers with Self-Prompt & Auto-Evaluation					X		
* Simulation Software Development & Test	X	X		X	X	X	
* Classroom Applications for Flight Controllers, Crew, and Customers					X		
* Facility & Data Link Scheduling					X		
* Prediction of Loss of Signal Times					X		
* Satellite System Scheduling					X		
* Fault Monitoring	X	X		X	X	X	
* Space Traffic Control Systems					X		
* Rescheduling Flight-Critical Operations					X		
* Adaptive GN&C System Support					X		
* All Subsystem Monitoring & Support	X	X		X	X	X	
* Real-Time Problem Solving, Malfunction Procedures Diagnostics	X	X		X	X	X	
* Telemetry Optimization Profiles					X		
* Telemetry Data Analysis				X	X		
* TM Trend Analysis & Development					X		
* Distribution of TM Data					X		
4.3.4 SPACE STATION SYSTEMS							
* Hybrid Robot/Teleoperator						X	
* Adaptive Control	X	X				X	
* Off-line Robot Programming thru CAD/CAM				X		X	
* Tactile Sensors (Arrays, Force Feedback)						X	
* Advanced Machine Vision						X	
* Mobile Robot Guidance/Navigation						X	
* Advanced Planning for Robots				X		X	
* Dual Arm Robotics				X		X	
* Dextrous Manipulator				X		X	

4.3.4 SPACE STATION (CONT.)

	LV	ORB	FACIL	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* Robot Application Modeling by Visual Simulation						X	
* Diagnostic Expert System	X	X		X	X	X	
* Distributed Computing	X	X		X	X	X	
* Advanced Data Storage Technology	X	X		X	X	X	
* Intelligent Man/Machine Interfaces	X	X		X	X	X	
* Intelligent Remote Sensor Technology		X				X	
* Energy Management/Advanced Process Control		X				X	
* Advanced Fault-Tolerant Disciplines	X	X		X	X	X	
* Advanced Data Display Techniques	X	X		X	X	X	
* Fault-tolerant Algorithms	X	X		X	X	X	

4.4 AVIONICS

	LV	ORB	FACIL	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* Automated Self-Check	X	X		X	X	X	
* Vehicle Health Monitoring System	X	X				X	
* GO2/GH2 Attitude Control System	X	X				X	
* SRM Thrust Vector Control	X						
* New Low-Cost Flight Control	X	X					
* Fault-Tolerant & Self-Check/Self-Healing	X	X				X	
* Flight Software Cost & Reconfiguration Time Reduction				X	X	X	
* Integrated Mission Planning, Targeting & Flight Software Development		X			X	X	
* Expert Systems	X	X		X	X	X	
* Flight Software Cost Reduction	X	X		X	X	X	
* Advanced Navigation Sensors		X					
* Adaptive GN&C	X	X					
* Autonomous Systems	X	X		X	X	X	
* High Landing Accuracy & Control		X					
* Advanced Information Processing	X	X		X	X	X	
* Integrated Avionics System Architecture (Pave Pillar/WPAFB-AFWAL)	X	X				X	

	LV	ORB	FACIL	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
4.5 AVIONICS (CONT.)							
* Fiber Optics Sensors for Motion, Displacement, Fluid Level, Fluid and Flow	X	X				X	
* Smart Sensors	X	X				X	
* Application-specific Integrated Circuits (ASIC) to implement BIT	X	X				X	
4.5 POWER							
* High Power Density Fuel Cell	X					X	
* Advanced APU	X	X					
* Nuclear						X	
* Regenerative Fuel Cell (RFCS)		X				X	
* Solid-oxide Fuel Cell (Honeycomb)	X	X				X	
* IPV Ni-H2 Battery						X	
* Bipolar Ni-H2 Battery						X	
* Ni-Cd Battery						X	
* Na-S Battery		X				X	
* Li-So2 Battery						X	
* Li-SOCl2 Battery						X	
* Li-TiS2 Battery						X	
* Solar Cells						X	
* Flywheels						X	
* High Temperature Superconductors	X	X				X	
4.6 PROPULSION							
* Advanced Reusable LO2/LH2 Engine	X	X					
* Advanced Reusable LO2/HC Engine	X	X					
* Advanced Expander LO2/LH2 Space Engine	X	X					
* LO2/RP1/Methane	X	X					
* Subcooled Propellants	X	X					
* Improved Solid Propellants	X						

4.6 PROPULSION (CONT.)

	LV	ORB	FACIL	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* Improved Motor Cases & Linings	X						
* Solid Rocket Motor Nozzles	X						
* Cryogenic RCS	X	X				X	
* Space-based Service/Maintenance		X	X		X	X	
* All Electric Engine Control	X	X					
* Mass-Produced Expendable Engines	X						
* Variable Thrust Engine	X	X					
* Advanced Solid Booster (Low Contaminants, Large Diameter/length, High Specific Impulse, Nozzleless)	X						
* Air Breathing (Scramjet, Ramjet, Turbo-ramjet; Air Augmented, Combined Cycle)	X	X					
* Hybrid (solid/liquid) Engine	X						
* Slush Hydrogen	X	X					
* Jelled Propellants	X	X					
* Dual Fuel Engine	X	X					
* Electric Propulsion		X					
* Laser Sustained Detonation (LSD)	X						
* Solid Motor OTV	X						
* GO2/GH2 Auxiliary Propulsion		X					
* Combined Cycle Engine with Lace-Fan, Rocket, Air Liquification & Jet Subsystems	X	X					
* Remote, On-orbit, Propellant Mgmt. & Transfer					X	X	

4.7 STRUCTURES & MATERIALS

	LV	ORB	FACIL	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* Adverse Weather Protection & Operations				X			
* CFD for Hypersonic Heat Transfer	X	X					
* Al-Li Structural Alloys	X	X					
* SiC/Al Composite Structural Materials	X	X					
* Gr/Mg Composite Structural Materials	X	X					
* High-Temperature Aluminum Alloys	X	X					

	LV	ORB	FACIL	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* SiC Foam Sandwich	X	X					
* Advanced Fiber Blanket TPS (2300F)		X					
* Large, Lightweight Tanks	X	X					
* Improved Cryogenic Storage	X	X					
* Large, Low Cost Expendable Structure	X	X					
* Advanced Reusable TPS	X	X					
* Flexible Ceramic Blanket TPS	X	X					
* High-Temp, High-Strength Hot Structures	X	X					
* High-performance Space Cryo Thermal Insulation	X	X				X	
* Ordered Polymer Resins	X	X					
* Rapid Solidification Mg & Al High Temperature Structures	X	X					
* Metallic & Ceramic Hot Airfoil Structures	X	X					
* Metal Matrix Composites (MMC)	X	X					
* Thin Carbon-Carbon Hot Structures	X	X					
* Refractory Matrix Composites	X	X					
* Carbon-Carbon or Metallic Mesh Aerobrake	X	X					
* Large-Scale Parafoil Technology	X						
* Non-Ordnance Separation & Range Safety Devices (Clevis/Acceleration, EM, Nitinol and Lasers)	X	X				X	
* Magnetic Suspension & Balance Systems		X				X	
* Actively Cooled Structures	X	X					
* XD Composites	X	X					
* RSR Beryllium	X	X					
* RSR Titanium	X	X					

4.8 OTHER

	LV	ORB	FACIL	LAUNCH OPS	MISSION OPS	SPACE STATION	RISK INDEX
* ULCE (Unified Life Cycle Engineering)	X	X	X	X	X	X	
* Auto Assembly & Test	X		X	X	X	X	
* Launch Site Manufacturing	X						
* Fiber Optics		X				X	
* Orbital Servicing/Ops		X					
* Automated Robotic Lay-up Processing for Composite Materials	X	X	X				

5.0 DESIGNERS CHECKLISTS

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5.0 DESIGNERS CHECKLISTS

NOTE: When using these Designer Checklists, please keep the following in mind:

* **If top level SYSTEM ENGINEERING recommendations are followed using the new technologies, these detailed DESIGN CHECKLISTS should be, for the most part, simply a checklist of past problems.**

* All items are not pertinent to every system.

* Some items are contradictory. For example, an item may be applicable to most designs but not be appropriate for your specific application.

* While many items appear to be obvious, they're included in the checklists because designs have these problems in recent hardware.

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5.1 ACCESSIBILITY CHECKLIST

SYSTEM: ______________________
SUBASSEMBLY: ______________________
ENGINEER: ______________________
ORGANIZATION/DESIGN BUILD TEAM: ______________________

	APPLICABLE Y/N	REMARKS
1. Accesses located to facilitate maintenance.		
2. Orbital access considers zero-G environment.		
3. Access is not hindered by installation.		
4. Accesses allow crew members to see what they are doing.		
5. Visual access is provided where needed.		
6. Uncovered accesses employed wherever practical.		
7. Access size and shape appropriate for work to be performed.		
8. Accesses allow for various tasks, clothing, accessories, tools.		
9. EVA accesses allow for operations and anthropometry.		
10. Frequently accessed units are on slides, hinges, roll-outs.		
11. Direct, quick access is provided to all test and service points.		
12. Small accesses use hinged, sliding, quick-open plates or caps.		
13. Massive items can be slid out rather than lifted out.		
14. Access will not cut personnel, clothing, etc.		
15. Guards and shields protect personnel from high voltages, etc.		
16. Safety interlocks are provided on access to all hazards.		
17. Switches can override interlocks if maintenance requires unit on.		
18. Each access location uniquely identified for instruction reference.		
19. Labels identify hazards, test or service points behind accesses.		

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5.1 ACCESSIBILITY CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
20. Labels in full view and appropriately placed.		
21. Labels identify equipment/material behind or used at access.		
22. Labels on small accesses show proper insertion of tools/spares.		
23. Access covers and fasteners conform to preferred types and practices.		
24. ORU removal involves minimum covers, fasteners, mounts, etc.		
25. Access doors shall not be load bearing.		
26. Access doors shall be designed keeping attachment hardware to the minimum required.		
27. Use easily changed "plug-in" printed circuit boards wherever possible.		
28. Keep frequently adjusted components easy to access.		
29 Frequently accessed panels use quick action fasteners that are easy to reach.		
30. Provide sufficient spacing between connectors so they may be grasped easily for connecting and disconnecting.		
31. Design equipment so that components with high probability of failure are the most easily accessible.		
32. Avoid stacking of parts. Replaceable units should be mounted to the chassis rather than to each other.		
33. Provide handles or bales for removing units of chassis from enclosures.		
34. Design equipment to permit thorough visual inspection of parts so that obvious failures can be located quickly.		
35. Where practical, provide for maintenance without the use of tools.		
36. Minimize the need for special tools.		
37. Redundant ORU/circuit breakers, etc., should be replaceable with system hot (where possible).		

5.2 AVIONICS CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Equipment should be rack-mounted width hand-operated captive fasteners to hold LRU in place.		
2. Equipment removal frequency should be considered when locating equipment in the vehicle. Access doors, covers, latches & fasteners combination should follow Structures Checklist in this document.		
3. Equipment with a high removal frequency should be situated in convenient locations to facilitate access.		
4. Large, bulky, and heavy equipment should be located at a convenient height so as not to require stooping, bending or kneeling for its removal.		
5. The design should eliminate the need to remove ancilliary equipment, such as a mounting rack, to effect removal of a black box unless the mounting rack and black box are considered as one assembly.		
6. Movement of handles, switches, cowls or guards to gain access to equipment should be avoided.		
7. Rear-mounted connectors should not require the unit to be held while it is being connected or disconnected.		
8. The need to obtain access to more than one compartment or area to accomplish the removal or installation of an assembly should not be required.		
9. LRU's should have handles to facilitate removal and transportation.		
10. Scoop-proof connectors should be used to provide proper alignment and prevent bending of pins.		
11. On-vehicle maintenance adjustments, alignments, or calibrations should not be allowed. If these are required for off-vehicle maintenance, they should not be accessible with the equipment installed on vehicle.		

	APPLICABLE Y/N	REMARKS
12. The equipment should incorporate features such that it is mechanically and electrically impossible to install equipment incorrectly, or to attach cables, tubes, electrical plugs, etc. in an improper manner. Mechanically keyed mating, different size connectors, etc., should be incorporated to eliminate all such possibilities. Shape of tubing, tie-down provisions, color codes, labeling, etc., should not be used as primary methods of satisfying this requirement.		
13. Equipment should be designed such that on-vehicle maintenance can be performed by personnel wearing protective clothing (masks, heavy gloves, etc.)		
14. There should be no requirement for scheduled maintenance (including inspections & parts replacement) for avionics equipment.		
15. All LRU installation hardware should be captive to prevent loss during vehicle maintenance.		
16. BIT/BITE equipment should be used to reduce fault isolation and function checkout time.		
17. GSE should be evaluated and considered at same time as vehicle equipment.		

5.3 BREAKERS & FUSES CHECKLIST

SYSTEM: ______________________
SUBASSEMBLY: ______________________
ENGINEER: ______________________
ORGANIZATION/DESIGN BUILD TEAM: ______________________

	APPLICABLE Y/N	REMARKS
1. Fuses or circuit breakers protect both sides of the line.		
2. Fuses/circuit breakers are located/grouped for easy inspection.		
3. Fuses/circuit breakers positively indicate when blown/tripped.		
4. Easily reset circuit breakers are preferred, usually to fuses.		
5. Tripped breakers are easily detected and reset from front panels.		
6. Breakers serving same functions are the same size, type and shape.		
7. Instructions for closing tripped breakers are clear and standard.		
8. Breakers are labeled with function and key characteristics.		
9. Fuses are on front panels and are replaceable without tools.		
10. Fuse applications are standardized in a few discriminate types.		
11. Fuses with replacement parts are used only in unusual cases.		
12. Enable fuse changeout/circuit breaker reset without disturbing system integrity.		
13. Provide overload indicators on major components even if overloaded circuits must sometimes be kept in operation.		
14. Provide a positive indication on the front panel that a fuse or circuit breaker has opened a circuit.		
15. Provide holders for spare fuses in a convenient location, and mark "SPARE".		
16. Select circuit breakers capable of being manually operated to the ON and OFF positions.		

5.4 COMMONALITY CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. A minimum number and variety of standard fasteners are used.		
2. Different thread types are discriminately different in diameter.		
3. Standardized 7/16 inch hex-heads are used wherever practical to minimize tools.		
4. "Identical subassemblies" are interchangeable without realignment.		
5. Like subassemblies with different functions are not interchangeable.		
6. Standardized, preferred circuits are used for routine functions.		
7. Common interface mating hardware and interfaces common to all payloads.		
8. Use standard off-the-shelf parts. (MS/NAS standards).		
9. Standardize components where possible, but don't make system more complex because of it.		
10. Where possible, ensure all repair piece parts are standard off-the-shelf.		
11. Strictly enforce the use of standard tools.		
12. Design specifications must establish a requirement for standardized panel fasteners.		
13. System specification should require all electric system LRU's should have quick disconnect capability.		
14. Project offices must review design inputs during CDR and PDR, proliferation of non-standard cable and connectors increases support costs, maintenance man-hours, technical data and training.		

5.5 CONNECTORS CHECKLIST

SYSTEM: ____________________
SUBASSEMBLY: ____________________
ENGINEER: ____________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Connectors are provided wherever equipment separation is likely.		
2. Quick-disconnect or plug-in connectors are used where feasible.		
3. Connectors are visible, reachable, operable without disassembly.		
4. Connectors are operable by hand and EMU glove, replaceable with common tool		
5. Adequate workspace and tool clearance surrounds each connector.		
6. Connecting auxiliary and maintenance equipment requires no tools.		
7. Each connector can be removed without disturbing others.		
8. Rear of plug is accessible for testing where practicable.		
9. Adapters are provided if needed for test/auxiliary equipment.		
10. Connectors are designed, placed, coded to prevent misconnection.		
11. Delicate parts are protected and overtightening is prevented.		
12. RU's are never soldered in and plugs not safety wired.		
13. Connector mounting points are supported against breakage.		
14. An open connector is obvious, but design prevents shorting.		
15. Connector leads are replaceable.		
16. All receptacles, terminal boards, etc., are readily replaceable.		
17. Extra connectors, pins, receptacles are provided as appropriate.		
18. Dust caps are supplied to protect connectors when not in use.		

	APPLICABLE Y/N	REMARKS
19. Plugs and receptacles are clearly identified by color, tags, etc.		
20. Connector labels/codes correlate with function, jack, diagrams.		
21. Strips, arrows, etc., indicate position for proper insertion.		
22. Plugs/receptacles are provided with aligning pins or devices.		
23. Aligning pins in uniform position, extend beyond electric pins.		
24. Pins are clearly coded and are arranged in standard fashion.		
25. Symmetrical pin arrangements are keyed to prevent misconnection.		
26. Provide standard connectors so that only a few adapter cables will be required for testing.		
27. Connector adjustment points should be permanently, simply and positively identified.		
28. Standardize wire, connectors and pin size early so that break out boxes are held to a minimum.		
29. Ensure connectors are properly designed for corrosive environments.		

5.6 ELECTRICAL POWER CHECKLIST

SYSTEM: ____________________
SUBASSEMBLY: ____________________
ENGINEER: ____________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Connectors should be used to a maximum extent. Splicing should not be required to replace an electrical component. Provide connectors at each bulkhead wire or harness passes through.		
2. Connectors should incorporate features to assure that it is impossible to incorrectly mate.		
3. Connectors should not require tools for connection.		
4. All instruments and console-mounted equipment should have sufficient service loops to allow equipment removal without removing other equipment or panels.		
5. Quick access to vehicle batteries should be provided.		
6. Quick access should be provided to power panels.		
7. Circuit breakers should be removable on vehicle without having to remove the power panel.		
8. Standardize connectors.		
9. Design cable harnesses so they can be factory-build and installed as a unit.		
10. Provide guards for easily damaged coaxial cables.		
11. Route cables to avoid sharp bends.		
12. Do not allow unprotected cables on floor panels.		
13. Protect ends of cable from moisture.		
14. Provide cable drip loops where appropriate.		
15. Protect cables from grease, oil, propellants, hydraulic fluid, water, etc.		
16. The need to remove a tie wrap from a wire bundle should not be required to accomplish removal or installation.		
17. Use moisture-proof connectors, not terminal strips.		

	APPLICABLE Y/N	REMARKS
18. Electrical harnesses shall be supported using metal brackets riveted to the structure. Posts bonded to the structure with adhesive should not be used.		
19. Engine-driven electrical generators should be mounted to the engine or structure mounted gearbox with a V-bound clamp to facilitate replacement.		
20. BIT/BITE should be used to reduce fault isolation and functional checkout time.		

5.7 ENGINE CHECKLIST

SYSTEM: ____________________
SUBASSEMBLY: ____________________
ENGINEER: ____________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Use all electric engine control.		
2. Removal/installation of the engine can be accomplished with the vehicle in a vertical or horizontal position.		
3. Engine changeout procedures should not require technicians to lie on the ground/floor to perform any tasks and should not require extraordinary dexterity.		
4. Engine access doors, latches and fasteners should be the combination which facilitates the lowest engine changeout time.		
5. Quick disconnects should be provided for all electrical, propellant and fluid connections necessary for engine removal (QD's must be qualified for environment).		
6. Quick-acting engine mounts should be used and engine mounts should be readily accessible.		
7. The method of attachment of the engine to the vehicle should be such that precise manual alignment of the engine with the vehicle is not required. The engine/vehicle mounting hardware should self-align the engine.		
8. The engine control connection should be a quick disconnect type.		
9. Engine control adjustment should be readily accessible. No adjustment after engine change should be required.		
10. The engine control should be secured by a single bolt and not require lockwire.		
11. On-vehicle engine trim capability should be provided. Access to adjustment should be unrestricted.		
12. On-vehicle engine borescope capability should be provided.		
13. Access should be provided for adjustment of rigging points.		
14. Ready access should be provided to all accessories. As a goal, removal & replacement of accessories should not require removal of the engine or other accessories.		
15. Ready access should be provided to all items that have to be inspected (chip detectors, differential pressure indicators, history recorder).		

	APPLICABLE Y/N	REMARKS
16. The engine shipping trailer, with the suitable adapters, should be used to remove/install the engine.		
17. "Pin-type" thrust mounts should be utilized. The thrust mounts should be secured in place by a simple clamp and TBD nuts. No lockwire should be required.		
18. The side load link should be attached to the engine by an expandable bolt to eliminate bolt hang-up or galling.		
19. The side load link should pivot out of the engine removal envelope such that need not be removed from the vehicle during engine change.		
20. The vehicle accessories (electrical generator, etc.) should be mounted on a structural member mounted gearbox. Accessories and accessory connections should not be disturbed during engine change.		
21. The engine should fit any position on the vehicle without reconfiguration.		
22. The goal for engine removal and replacement time is ___ hours using ____ technicians.		

5.8 FASTENERS CHECKLIST

SYSTEM: ____________________
SUBASSEMBLY: ____________________
ENGINEER: ____________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. A minimum number and variety of standard fasteners are used.		
2. Fasteners are large, strong, durable, and "freeze" proof.		
3. Fasteners can be reached and removed without other disassembly.		
4. Different thread types are discriminately different in diameter.		
5. Standardized 7/16 inch hex-heads are used wherever practical to minimize tools.		
6. Like fasteners in different lengths are never used together.		
7. The number of turns to remove fasteners is minimal (4 or less).		
8. Adequate working and tool clearances surround each fastener.		
9. Special fasteners in different lengths are never used together.		
10. Standard size, type, torque value codes are etched or embossed.		
11. Frequently used fasteners contrast in color with the surface.		
12. Replacement of stripped, worn, damaged fasteners is easily accomplished by hand and EMU glove using common hand tools.		
13. Combination heads (deep slot and hex) allow alternate tool use.		
14. Winged nuts are preferred to knurled nuts; avoid tapped holes.		
15. Captive fasteners are used where loose items could create problems.		
16. Washers/seals fit tightly; are durable; used only in a few standard sizes.		

	APPLICABLE Y/N	REMARKS
17. Rivets are not used on any part that may require removal.		
18. Safety wiring/cotter keys are avoided; can be replaced if used.		
19. Close tolerance fasteners are avoided.		
20. Nut plates are easily aligned; each ganged nut is replaceable.		
21. Retainer chains/rings prevent loss of small items, hold covers.		
22. Chains are located externally; can not engage moving gear, etc.		
23. Chains are no longer than necessary; bead-link chain avoided.		
24. Plug-ins, hinges, catches, etc. reduce number of fasteners used.		
25. Zero-force fasteners used where appropriate.		
26. Phillips, common and allen head screws are avoided.		
27. Use twist lock/snap fasteners where threaded connections might loosen.		
28. Avoid the use of self-tapping screws.		

5.9 FLUID SYSTEMS CHECKLIST

SYSTEM: ______________________
SUBASSEMBLY: ______________________
ENGINEER: ______________________
ORGANIZATION/DESIGN BUILD TEAM: ______________________

	APPLICABLE Y/N	REMARKS
1. Rocket engine mass (heat sink) must be chilled down prior to filling flight tanks to avoid destructive geysers and surging.		
2. Fill and drain lines must be sized with adequate pressure rating to accommodate reasonable servicing time.		
3. Gas and liquid traps must be avoided to accommodate reasonable servicing time and minimize flight to ground interfaces.		
4. Structural designs that require thermal conditioning must be avoided to accommodate reasonable servicing time.		
5. Fill and drain interfaces must be designed to avoid destructive ullage gas collapse during chilldown and filling.		
6. Consideration must be given to excess hydrogen from engine exhaust during ground operations.		
7. Ground facilities must avoid traps and containment of free hydrogen to avid fires and explosions.		
8. Contamination control must be considered with emphasis on designs that can accommodate large particles - screens and baffles may impact servicing time. Also location of screens should be driven to reduce the impact on ground servicing and not be based on minimum weight/performance.		
9. External insulation used on cryogenic tanks and lines must consider cryo pumping of air when used for LH2 service. This cryo pumping will destroy the insulation and generates a safety concern.		
10. Purging and drying of tanks, cryo transfer systems, engines, and cooling/heat transfer systems must be considered to avoid freeze-up and contamination.		
11. Consideration must be given that cryogenic systems generate frost and ice which can cause structural damage and added weight.		
12. Consideration must be given that the use of large quantities of inert gas (GN2 and He) used to control environments creates safety and cost concerns. STS cost for GN2 and He each commonly cost twice, or more, the expenditure on LOX for a given period of time.		

5.9 FLUID SYSTEMS CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
13. Be aware that high velocity He flow quickly creates high temperature in interconnecting pipe lines.		
14. Us of GN2 and He should be minized, not only as a safety precaution, but also from a cost concern. The money value for these gases as used at KSC is surprisingly large. In Nov. 1985, a common or typical month, the SPC spent the following on propellants and gases: LH2 @ \$1.35/lb — 430K lb - — \$580,000 LO2 @ \$86/ton — 1910 tons - — \$168,500 MMH @ \$8/lb- — 32,480 lb. — \$226,600 GHE @ \$56/MSCF — 5,930 MSCF - — \$332,100 GN2 @ \$6/MSCF — 65,000 MSCF- — \$390,000		
15. Consideration must be given to insulation debond on cryogenic tanks from expansion of pressure vessel surface as the tank stretches when pressurized and induces high stress in the bond line. Shuttle ET workaround is to service underpressure which locks in the stress so that tank can be pressurized and depressurized with only a small delta stress.		
16. Be aware of component fretting which is caused by high velocity flow induced vibration of internal parts.		
17. Be aware of possible component internal combustion which is caused by microscopic particle impacts in a GOX flow stream.		
18. Be aware of fluid valves that are susceptible to flow induced failure mode (close under flow instead of remaining in last position with actuator failure).		
19. Be aware that cryogenic valve position verification by actuator does not always verify position. This is still a problem for shuttle.		
20. Lack of standardization of components from one discipline to another increases operations cost unnecessarily.		
21. Lightweight cryo valves require anti-slam provisions to avoid damage. This increases complexity of the component and added failure modes, i.e, weight shouldn't be the sole design driver.		
22. Be aware that late or inadequate qualification testing of components results in many changes in hardware and increased O&M.		
23. Inadequate design margin for performance (sometimes caused from not allowing for adequate growth) in major hardware elements increases O&M considerably (dynamic systems require considerably more unscheduled maintenance).		

	APPLICABLE Y/N	REMARKS
24. Be aware that the lack of design integration (overall vehicle) requires more commodities to be procured, stored, and serviced (adding many more interfaces) and this results in a very great operational impact (schedule time, manpower, and cost) to the program.		
25. Consummable operated systems prior to launch constrain the hold and recylce capability and should be avoided or properly considered when design sizing is accomplished.		
26. If hydraulic controls are required for technical reasons and not just based on weight trade and experience, they should be self-contained modular units.		
27. Avoid placing high pressure dynamic systems in closed compartments as they require the compartment to be environmentally monitored both on the ground and inflight to provide safe operation of vehicle.		
28. The use of mechanical joints and the absence of isolation devices between high pressure and low pressure systems require much manpower and ground checkout time to perform leak checks.		
29. Fluid ducts designed with weight as the driver can experience deformation from cryo cycles and require changeout. This is generally caused by insulation leaks and is not detectable by normal external inspections.		
30. Avoid designs that do not allow single ground failure of instrumentation prior to flight, i.e., all sensors used for red-line functions should be dual redundant.		
31. Flow induced vibrations in flex hoses and bellows should be avoided by design as they can result in failure from fatigue. - Such a failure at LC-39A during early Apollo-Saturn resulted in the spill of about 600K gallons of LOX		
32. The vehicle design should avoid or minimize OMRS and launch commit criteria type requirements as those requirements drive a large manpowered effort and reduce probability for launch.		
33. Avoid labor intensive designs, i.e., like Orbiter TPS - Bondline question - Moisture level question - Susceptible to damage		
34. Avoid vehicle designs that are "only 0-G Systems" as they require GSE aids that add ground time and manpower.		

	APPLICABLE Y/N	REMARKS
35. Be aware that composite structural materials are sometimes susceptible to moisture that results in damage when subjected to space environment.		
36. Like airplanes, a reusable vehicle requires much ground testing and inspection (redundant systems and components verification) because of inadequate health monitoring and built-in diagnostic capability. Also the accessibility for inspection, repair, or changeout must be considered in initial design as these deficiencies result in ground testing, checkout, and considerable maintenance time and manpower being required.		
37. VJ ducts have been successfully manufactured with one ATM pressure of Argon gas in the annular space. These ducts are less sensitive to small leakage when not in cryo use and are relatively short. Super insulated lines (foam with Nickel) where exposure to cryo is relatively long are more susceptible to damage.		

5.10 PACKAGING CHECKLIST

SYSTEM: ______________________________
SUBASSEMBLY: ________________________
ENGINEER: ___________________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Package in single layer-arrangement (no stacking of ORU's.		
2. Number of inputs/outputs and criss-cross signals is minimized.		
3. Delicate items are located/guarded against damage or misuse.		
4. Components are segregated by maintenance skills and tasks where possible.		
5. Packaging minimizes place-to-place movements of the crew member.		
6. Adequate workspace is provided for tools/test/service.		
7. EVA ORU's are R&R by EMU glove, using common hand tools.		
8. Like items are grouped together and mounted in uniform fashion.		
9. ORU's are removable along straight or slightly curved lines.		
10. ORU's are not concealed; manner of mounting is always obvious.		
11. High failure rate and serviceable items are most accessible.		
12. Large items, cables, mounts, do not impede access to ORU's.		
13. Plug-in, snap-on items are replaceable without interference.		
14. Sequential assembly requiring sequential disassembly is avoided.		
15. All plug-in sockets, keys, are oriented in the same direction.		
16. Guides/pins assist mounting, particularly of self-contained ORU's.		

5.10 PACKAGING CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
17. No functioning parts or ORU's are permanently attached.		
18. ORU's are independently mounted and blind mounting is avoided.		
19. ORU's cannot be incorrectly mounted; (staggered holes, etc.).		
20. Mounting requires a minimum number of standardized fasteners.		
21. Plug-in, quick-disconnect fasteners are used when possible.		
22. Locking pins, shock mounts, tie-downs are used where needed.		
23. LRU's should be replaceable without powerdown.		
24. Package on single layer-arrangement (no stacking of ORU's).		

5.11 RELIABILITY CHECKLIST

SYSTEM: ______________________
SUBASSEMBLY: ______________________
ENGINEER: ______________________
ORGANIZATION/DESIGN BUILD TEAM: ______________________

	APPLICABLE Y/N	REMARKS
1. Essential systems need to be completely independent of other systems and sub-systems.		
2. Examine system for weakest link and strengthen it, repeating until optimized.		
3. Perform reliability predictions to determine probable failure mode before design parameters are frozen.		
4. Minimize use of moving parts.		
5. Use fail-safe features. Minimize the possibility of any faulty part causing an unsafe condition, a series of other parts to fail, or complete equipment failure.		
6. Use parts whose dominant failure mode has a minimum effect on the output of the circuit.		
7. Make circuits and mechanical designs as simple as practicable.		
8. Keep number and complexity of individual stages to an absolute minimum.		
9. Keep the number and variety of components (electrical and mechanical) to an absolute minimum.		
10. Utilize common parts where possible. Insure complete interchangeability of all like removable parts.		
11. Use adequate derating factors for temperature effects (especially with semiconductors, capacitors and resistors) to insure reliability under worst case conditions.		
12. Compensate in equipment design for known limitations of parts.		
13. Choose relays and switches with the proper contacts considering peak current to be interrupted, lowest current to be conducted, and a maximum acceptable contact resistance.		
14. Use tolerances which allow for use and wear throughout equipment lifetime.		
15. Eliminate critical circuits by allowing large tolerance margins in circuit operation.		

	APPLICABLE Y/N	REMARKS
16. Do not push state-of-the-art technology if readily available, proven reliable, common-use technology will do the job.		
17. Minimize use of parts known to have high failure rates, such as connectors and relays.		
18. Do not employ active elements if a function can be performed entirely by passive elements unless designing microcircuits.		
19. Prevent possible open circuits in variable resistors by connecting the wiper to one end whenever that end would otherwise be left unconnected.		
20. Be certain that resistor wattage rating is still adequate when adjusted toward minimum resistance.		
21. Use a single connector pin of adequate current rating rather than dividing the current between several pins of lower rating.		
22. Minimize power supply demands and internal temperature rise in equipment by using the lowest feasible values of current and voltage.		
23. Avoid circuits that require a high degree of voltage regulation.		
24. Do not load integrated circuit outputs to more than 70% of manufacturers maximum fanout rating.		
25. Do not exceed the manufacturers recommended power supply voltage. Maximum ratings should never be used.		
26. Protect wires and cables running through holes in metal partitions or across sharp metal edges from mechanical damage by the use of grommets or other suitable means.		
27. Route cables to protect them from damage during movement or from moving parts.		
28. Do not route electrical cables below fluid lines.		
29. Do not use edge-board connectors. Two-piece connectors are more reliable.		
30. Be sure that certain failure modes do not negate the use of redundant equipment.		

5.12 SAFETY CHECKLIST

SYSTEM: ______________________

SUBASSEMBLY: ______________________

ENGINEER: ______________________

ORGANIZATION/DESIGN BUILD TEAM: ______________________

	APPLICABLE Y/N	REMARKS
1. Allocate GSE to specific systems to avoid using the same equipment to interface with fuel, oxidizer and hydraulic systems. Clearly label equipment as to the systems it can be used to service.		
2. Required safety equipment shall be clearly identified.		
3. Provide adequate, fail-safe features for preventing injury to personnel and damage to equipment.		
4. It should be obvious how safety features operate.		
5. Safety features should be difficult to bypass or deactivate except for specific maintenance bypass circuits.		
6. Use conspicuous cautions and warnings with large, contrasting print.		
7. Provide a readily accessible means of removing all power to the equipment. This and other power switches should be located to prevent accidental operation of the equipment.		
8. Use current limiting resistors where appropriate for safety in high voltage circuits.		
9. Ground all external metal parts, control shafts, and bushings. Antenna or transmission line terminals should be at ground potential except with regard to to the energy to be radiated.		
10. Safeguard operating personnel from coming into contact with voltage in excess of 30 volts dc or rms. Do not locate adjustment screws or other commonly worked-on parts near unprotected high voltages.		
11. For potentials above 30 volts, provide discharging devices that actuate automatically when equipment is opened, unless capacitors discharge to 30 volts in 2 seconds or less.		
12. Resistive bleeder networks should consist of at least two equal resistors in parallel.		
13. Provide guards (marked with highest voltage), interlocks with bypass, automatic discharge devices, and grounding rods for potential between 70 and 500 volts dc or rms on contacts, terminals, and other similar devices.		

	APPLICABLE Y/N	REMARKS
14. Interlock bypass devices should have a clearly visible warning indicator (illuminated jewel). Bypass devices should reset automatically when the access is closed.		
15. Completely enclose assemblies with potentials exceeding 500 volts dc or rms. Clearly mark enclosures: "DANGER HIGH VOLTAGE (maximum voltage) VOLTS." Use white or aluminum color on red background. Provide interlocks without bypass, automatic discharging devices, and grounding rods, as applicable.		
16. When practicable, the leakage current of the equipment should not exceed 5 ma to ground. Where more leakage is unavoidable, a warning plate must be attached to the front panel reading: DANGER - do not energize this equipment unless frame and all exposed metal parts are grounded.		
17. Provide meters or voltage dividers with test points for measurement of voltage in excess of 300 volts peak. Voltage dividers should have at least two equal resistors in parallel between the test point and ground		
18. Do not connect meters in portions of circuits which will cause high voltage potentials between meter and front panel if meter should fail.		
19. Use panel meters having nonmetallic zero adjusters.		
20. For maximum safety, mount meters in high voltage circuits behind a window of glass or thick plastic.		
21. Provide screwdriver guides to adjustment points which must be operated near high voltages or thermally hot components, or are difficult to locate. Screwdriver handles should also be clear of obstructions and hazards.		
22. Specify special tools or adequate insulation for tools used near high voltages.		
23. Ventilation holes should be small enough to prevent inadvertent insertion of test probes or fingers.		
24. Exposed pins on plugs and receptacles should not be energized (hot). Only socket type contacts should be energized after unmating.		
25. Include a safety ground in all cable assemblies that plug into convenience outlets. Connect the grounding pin of a three pin conductor to the green wire of a three conductor cable (black/white/green).		
26. Keep microwave and X-radiation to safe levels and warn personnel with appropriate markings or labels.		
27. Provide large rotating assemblies with a local power safety switch.		

	APPLICABLE Y/N	REMARKS
28. Provide guards to protect personnel from moving mechanical parts such as gears, fans, and belts.		
29. Use rounded edges (0.04 inch min.) and corners (0.5 inch min.) on enclosures.		
30. Protect personnel from cutting edges, burrs, and pointed objects. Protrusions should be avoided, padded, or conspicuously marked.		
31. Use recessed handles rather than the extended type to conserve space, preclude injuries, and minimize catching on other units, wiring, or structures.		
32. Design locking mechanisms for doors and drawers to prevent injury to the operator when the lock is released. Accidental release of locks should also be prevented as this could cause injury to personnel or equipment damage.		
33. Protect personnel from imploding cathode ray tubes.		
34. Prevent toxic fumes, corrosive fluids which cause chemical burns, combustible mixtures, or explosive gases from reaching personnel, even if parts are damaged or broken.		
35. Specify nonsparking tools for use in flammable or explosive atmospheres.		
36. Equipment in a hazardous atmosphere should be properly enclosed (explosion-proof housing, hermetically sealed, embedded, or pressurized) and electrically bonded to ground.		
37. Design so that the temperature of any enclosed part, including enclosure, does not exceed 60 C at an ambient temperature of 35 C. Front panels and controls should not exceed 43 C.		
38. Do not locate thermally hot parts near commonly worked-on components.		
39. Avoid bare metal handles on tools or controls for use in extreme heat or cold.		
40. Beware of claims of flame-retardant, fire-resistant, or self-extinguishing plastics. If safety dictates such a requirement, test the actual application.		
41. Warn personnel by marking or labeling equipment using radioactive materials. Protect personnel from dangerous exposure.		

5.12 SAFETY CHECKLIST (CONT.)

Item	APPLICABLE Y/N	REMARKS
42. Keep audible noise as low as possible, but at least below safe exposure levels.		
43. Protect personnel from intense light such as from lasers and provide appropriate warning labels.		
44. Avoid locating panels with GN2 purges in enclosed areas.		

5.13 STRUCTURES CHECKLIST

SYSTEM: ______________________
SUBASSEMBLY: ______________________
ENGINEER: ______________________
ORGANIZATION/DESIGN BUILD TEAM: ______________________

	APPLICABLE Y/N	REMARKS
1. Different types of fasteners (screws, bolts, quick release) should be held to a minimum.		
2. Different size and length of fasteners should be kept to a minimum. All fasteners on an access door or cover should have the same diameter and grip length. If not possible to have the same grip length, bolts should be a different diameter.		
3. Goal of one (not more than two) fastener-head drive element types. Drive element should provide a positive engagement with the tool required for removal/instl.		
4. All access panels should be of sufficient size to allow maintenance on equip while wearing protective clothing.		
5. Quantity of fasteners minimized for each panel.		
6. Hinged doors used to provide quick access and limit damage due to ground handling and wind.		
7. Hinged access doors that hinge up should be provided with supports to retain doors in the open position.		
8. Hinged doors should clear the work area so that removed/replaced LRU's do not strike/deform structure during maintenance.		
9. Sealing methods should be used to prevent moisture intrusion between structure & access panels. Form-in-place gaskets are acceptable, but not sealant that must be applied to the surface of panels and screwheads.		
10. Hinge fittings should be bolted on and not be an integral part of control surface or any hinged surface. This facilitates hinge replacement.		
11. Drain holes should be provided in any area where liquids could be trapped.		
12. Rivets should be installed with wet sealant.		
13. Access covers & doors should be interchangeable between vehicles without modification or fitting.		
14. Covers should be completely removable and replaceable in case of damage.		

	APPLICABLE Y/N	REMARKS
15. If composite materials are used for access panels, the holes provided in the panel for fastener location shall be reinforced with material other than the composite to avoid the wearout and resultant corrosion caused by the fastener contact with the composite surface.		
16. Access openings for inspection, servicing and engine change should use thumb-latched hinged doors or hinged access doors with fast acting captive fasteners with hex drive.		
17. Minimum fastener diameter should be 1/4".		
18. Access should be provided to all points, items, units, and component which require servicing. Access should be provided with the minimum use of panels & covers.		
19. Fasteners for panels and covers should be minimal in number with the easiest possible method of operation.		
20. Stress panels should not be used unless there is no alternative available.		
21. Type, size, shape and location of accesses should be based on the following:		
+ Location, setting and environment of unit.		
+ Frequency of required access.		
+ Maintenance function to be accomplished.		
+ Clearance requirements.		
+ Minimum use of special tools/equipment.		
+ Distance hands must be extended into access.		
+ Visibility requirements.		
+ Size, weight, shape & clearance requirements of objects that must enter access.		

5.14 SUBASSEMBLIES CHECKLIST

SYSTEM: ______________________
SUBASSEMBLY: ______________________
ENGINEER: ______________________
ORGANIZATION/DESIGN BUILD TEAM: ______________________

	APPLICABLE Y/N	REMARKS
1. Subassemblies can be removed and replaced without disconnecting or removing other equipment and without introducing a hazardous condition.		
2. Subassemblies are packed with the greatest practical density.		
3. Subassembly design compatible with planned diagnostic capabilities.		
4. Subassemblies are tested as units on go/no-go basis for minimum error as practical.		
5. Subassemblies are sealed only if assembly requires special conditions.		
6. "Identical subassemblies" are interchangeable without realignment.		
7. Like subassemblies with different functions are not interchangeable.		
8. Piece parts are mounted on, or integral to subassemblies.		
9. Parts are mounted in an orderly array and are not stacked.		
10. All parts in a subassembly contribute to a single, common function.		
11. Critical items or parts subject to R&R are not encapsulated.		
12. Irregular hoses, waveguides, etc., are removable before handling.		
13. All connections are failsafe, and will tolerate jumper cables.		
14. A system-consistent color-code discriminates similar modules.		
15. Codes and labels identify and outline functional groups of items.		
16. Test and service points, their values and limits, are labeled, where practical.		
17. Lift points are indicated; circuits are shown on sealed networks.		
18. Standardized, preferred circuits are used for routine functions.		

5.15 SUPPORT EQUIPMENT CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Work stations and accessories designed for zero-g are provided as needed.		
2. Work stations include storage for patch cords, testers, tools, manuals, spares and miscellaneous items.		
3. Work stations contain necessary communications, video, and lighting.		
4. Equipment restraints, racks and drawers are provided where needed.		
5. Restraints are compatible with accesses, slide rails, etc.		
6. Where possible, restraints are part of basic rack/console.		
7. Restraints, holders, reels, etc. are built-in wherever practical.		
8. Crew restraint eyes, hooks, pulleys, etc. are provided where needed.		
9. Crew restraints, belts, clothing, goggles are provided/stored where needed.		
10. Support equipment is built-in or portable (in that order).		
11. Portable items are human engineered for zero-g posture and are easy to use, carry, and store.		
12. Handles, retainers, bumpers are provided to reduce hazard of accidental contact.		

5.16 TEST EQUIPMENT CHECKLIST

SYSTEM: ______________________________

SUBASSEMBLY: __________________________

ENGINEER: _____________________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Adequate/standard TE is planned for each required measurement.		
2. TE is designed and shielded for constant, rough use.		
3. TE is selected/planned for operations, workspace and environment.		
4. TE is built-in where use is heavy, access and displays limited.		
5. TE is fail-safe; failure is not dangerous to people or equipment.		
6. Grounds, breakers, and fuses protect against user error/misuse.		
7. TE allows one-person troubleshooting in fewest and quickest steps.		
8. TE allows access to inputs/outputs of each RU, module, etc.		
9. Selector switches are preferred to many separate connectors.		
10. Probes can be comfortably held; tips ensure adequate contact.		
11. Major leads are permanently attached, and adequate in length.		
12. Removable adapters are provided as needed for flexibility.		
13. Simple checks show when TE is out of calibration or in error.		
14. Displays are direct reading; any conversion tables are on TE.		
15. TE is planned to satisfy as many related uses as possible.		
16. Instructions are permanently inscribed in step-by-step format.		

5.16 TEST EQUIPMENT CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
17. Instruction language is simple, in easy view and easily read.		
18. Instructions include calibration requirements and procedures.		
19. There is a label on every item personnel must use.		
20. Labels provide name, purpose, limitations and cautions for user.		
21. Color codes relate controls/displays and alternate scales/uses.		
22. Storage is adequate for leads, probes, spares, data, references, etc.		
23. Storage holders/fasteners are provided, proper use indicated.		
24. Portable TE is self-powered and best size/shape weight for use.		
25. All TE is designed for convenient storage, transport and repair.		

5.17 TEST POINTS (TP) CHECKLIST

SYSTEM: ______________________________
SUBASSEMBLY: __________________________
ENGINEER: _____________________________
ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Only TP's useful to check, detect and diagnose are provided.		
2. Major/intermediate/minor TP's differ in location/type/coding.		
3. The number of different types/sizes of TP's is minimized.		
4. TP's are consistent with maintenance concepts and techniques.		
5. TP's are provided for direct check at input and output of RU's.		
6. TP's are provided in all connectors, jacks and terminals.		
7. TP's for external test equipment are on outer case of units.		
8. TP's are fully exposed except where deliberate concealment is required.		
9. Special TP's are used only for depot maintenance functions.		
10. TP's are grouped on the most accessible face of each unit.		
11. TP's are grouped within limits of normal test lead lengths.		
12. TP's are arranged in a line/matrix reflecting test sequence.		
13. TP location precludes probe damage to lines and other items.		
14. Frequently used TP's are most accessible; all are visible.		
15. Trouble can be diagnosed without removing units or subassemblies.		
16. Adequate workspace is provided about TP's for probes, hands.		
17. TP's will support probes, which need not be held by hand.		
18. Probes, leads require only fraction turns for attachment.		

5.17 TEST POINTS (TP) CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
19. TP's are labeled with wave form, voltage, and tolerances.		
20. TP's are labeled sequentially and color coded to aid in location.		
21. Luminescent markings aid TP location in low illumination.		
22. TP attachment and construction will withstand long use.		
23. TP insulation and clearances prevent shorting with probes.		
24. Provide sufficient test points to allow fault isolation through the replaceable unit level.		

5.18 TESTABILITY CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Divide complex logic functions into smaller combinational logic sections.		
2. Avoid one-shots; if used, route their signals to the edge connector.		
3. Keep logic depth on any board to a low level by using edge-terminated test/control points.		
4. Use open collector devices with pull-up resistors to enable external override control.		
5. Construct trees to check the parity of selected groups of eight bits or fewer.		
6. Break paths when a logic element fans out to several places that converge later.		
7. Bring out test points as near to d/a conversions as possible.		
8. Provide a means of disabling on-board clocks so that the tester clock may be substituted.		
9. Provide mounted switches and RC networks with override lines to the edge connector.		
10. Route logic drives of lamps and displays to the edge connector so that the tester can check for correct operation.		
11. Separate analog circuits from digital logic, except for timing circuits.		
12. Add top-hat connector pins or mount extra IC sockets where there aren't enough edge connector pins for test/control points.		
13. Use sockets with complex ICs - CPUs, UARTs and long dynamic shift registers.		
14. Wire feedback lines and other complex circuit lines to an IC socket with a jumper plug so that they can be interrupted at test.		
15. Use jumpers that can be cut during debugging. The jumpers can be located near the board-edge connector.		
16. Allow for capacitive loads on input/output lines and test points.		
17. Allow for external initialization of internal circuitry.		

5.18 TESTABILITY CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
36. Standardize power-on and ground pins to avoid test-harness multiplicity.		
37. Divide large PC boards into subsections whenever possible.		
38. Uniformly mount ICs and clearly identify them to make it easier to locate them.		
39. Provide sufficient clearance around IC sockets and direct-soldered ICs so that IC clips can be attached whenever necessary.		
40. Fix locations of power and ground lines for uniformity among several board types.		
41. Make the ground trace on boards large enough to avoid noise problems.		
42. Group together signal lines of particular familiarity.		
43. Clearly label all parts, pins and connectors.		
44. Test power supplies.		
45. Provide immunity from transients and improper voltage application sequences.		
46. Use "zero" or low insertion-pressure connectors to extend the test life of test adapter connectors.		
47. Built-in-test (BIT) should be used for both fault detection and isolation.		
48. Fault indicators, both visual and audible, are desirable and must themselves be easily tested.		
49. Design test points and test connector to allow accidental shorting of pins both to ground and to each other without circuit damage.		
50. Design for rapid and positive adjustment and calibration. Adjustments should be accessible and easily identified.		
51. Provide methods of interrupting feedback loops.		
52. Design to avoid "Domino" failures.		
53. Design BIT circuitry to allow failsafe operation in case of BIT failure.		
54. Built-in monitoring devices/BITE should be easily removable for calibration and repair.		

5.19 WIRING CHECKLIST

SYSTEM: ____________________

SUBASSEMBLY: ____________________

ENGINEER: ____________________

ORGANIZATION/DESIGN BUILD TEAM: ____________________

	APPLICABLE Y/N	REMARKS
1. Wiring is designed to allow repair/installation in zero-G environment.		
2. Conductors are bound in pre-planned cables and harnesses.		
3. Wires within cables/harnesses are traceable by position/color.		
4. Cables and wiring are standardized in type, size, and fixtures.		
5. Wiring is protected in raceways, stuffing tubes, conduit, etc.		
6. Wiring is secured by quick-release nonconductive clamps/plates.		
7. Wiring is supported at both ends of bends and weak areas.		
8. Wire routing won't block access or interfere with maintenance.		
9. Wiring is protected from edges, fluids, and heat.		
10. Wiring is routed for tracking and repair and should avoid being pinched, walked-on, run-over, used for handholds, etc.		
11. Wiring bears no load and will disconnect before breaking.		
12. Wiring to moving parts permits easy movement without stress.		
13. Wiring lengths permit convenient testing or removal of units.		
14. Wiring need not be bent or unbent sharply when reconnected.		
15, Wiring is coded, labeled, tagged with type and source of signal.		
16. Wiring labeling and coding is consistent throughout the system.		
17. Cables and connectors will pass through walls, bulkhead, and runs.		
18. Needed extension cables (storage space and hooks) are provided.		

5.19 WIRING CHECKLIST (CONT.)

	APPLICABLE Y/N	REMARKS
19. Spare terminals, connector pins, and wires are provided.		
20. Leads fan out to provide workspace and to prevent misconnection.		
21. Lead lengths permit easy connection and connector replacements.		
22. Test points are provided if leads are unavailable for testing.		
23. Terminals will not loosen, rotate, or break with repeated use.		
24. Terminals are spaced so work on one does not damage others.		
25. Push-type terminals are used when possible.		
26. Ground connections should interface with an external panel.		
27. Connector design should eliminate/minimize "bent-pin" problems.		
28. If wiring will require protective covering, include covering in initial design.		
29. Mark transmission line terminals with the characteristic impedance of the line.		

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16. Abstract

This volume presents, in checklist format, the lessons learned from STS and other programs. The checklist items were compiled so the information would be easily usable for a number of different analytical objectives, and then grouped by disciplines or gross organizational, and/or functional responsibilities. Content of the checklists range from 27 management; 11 system engineering; 8 technology; and 19 design topics -- with a total of 793 individual checklist items. Use of this Handbook to identify and reduce Cost Drivers is recommended for designers, Project and Program managers, HQ Staff, and Congressional Staffs.

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